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LOG EXPORT RESTRICTIONS OF THE WESTERN STATES AND BRITISH COLUMBIA

by JOHN W. AUSTIN

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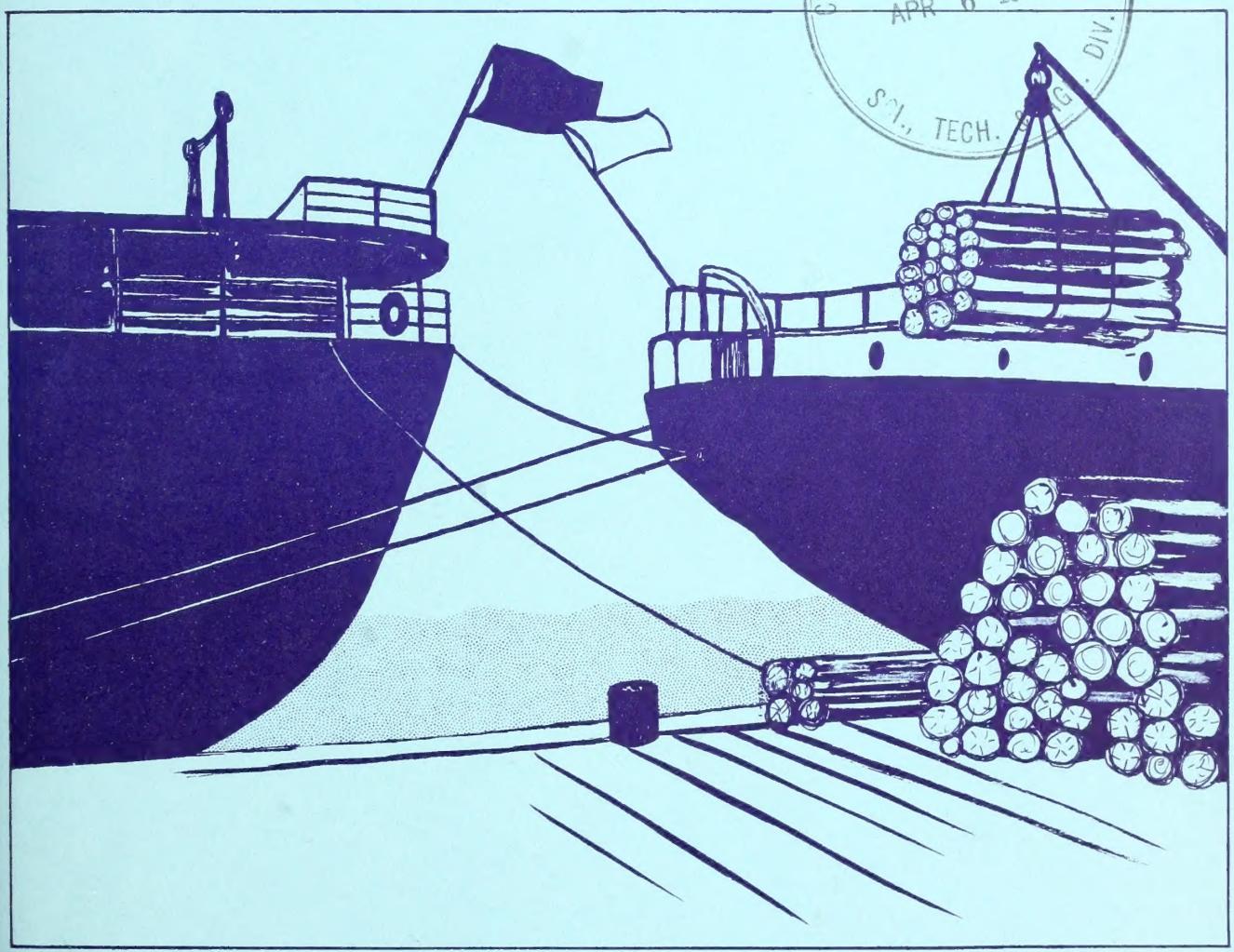

PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION
FOREST SERVICE U.S. DEPARTMENT OF AGRICULTURE
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The volume of logs exported from the Pacific Northwest has been widely publicized in the past few years. These exports, with the strong domestic market for wood products, have resulted in increasing demands on the Pacific Northwest's timber resources. In response to these pressures, various log export restrictions and primary manufacturing requirements for timber products have been proposed and enacted. This paper presents the main provisions of these export restrictions.

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JOINT DETERMINATIONS OF APRIL 22, 1968, BY THE
SECRETARIES OF AGRICULTURE AND INTERIOR

Log exports limited to 350 million board feet on Federal lands in western Washington and western Oregon

On April 16, 1968, the Secretaries of the Departments of Agriculture and Interior jointly issued determinations on log exports, effective April 22,[1/] covering Federal timber in western Washington and western Oregon and a few National Forest areas in the eastern portions of the two States. The eastern areas were included because of their economic relationship to the timber economy of the western areas.

These plans, which were to be effective until June 30, 1969, required that all but 350 million board feet of timber sold annually from certain designated National Forests and Bureau of Land Management (BLM) lands in the Pacific Northwest receive primary manufacture in the United States. The exempt volume was a combined judgment determination by the two Federal agencies of the volume that could be excepted from domestic manufacturing. Western Washington and western Oregon National Forests were allowed an annual exemption from the primary processing requirement of 290 million board feet (long log, Scribner scale) and the Bureau of Land Management was allowed an exemption of 60 million board feet on its western Oregon lands.

The National Forest portion was divided among the various forests according to estimated amounts of National Forest timber believed to have been exported from the producing zones during the previous year. The plan covered all Forest Service advertised sales with an appraised value in excess of $2,000.

The Bureau of Land Management allocated its 60 million board feet to the Bureau's five western Oregon districts in direct proportion to each district's allowable cut. Such exempt volume was allocated to individual sales of 100,000 board feet or larger, on a basis of approximately 5 percent of the contract volume for such sales. All western Oregon Bureau of Land Management timber sale contracts of 100,000 board feet or more required primary manufacture of approximately 95 percent of the contract volume to be done in Washington, Oregon, or California. Sales of less than 100,000 board feet required primary manufacture of all sale volume in the three-State area.

These log export restrictions applied to all species except Port-Orford-cedar which was declared surplus to domestic needs. Primary manufacture under these restrictions consisted of cants sawn on two sides, or squares that were 8 inches or less in thickness through the sawn dimension, and smaller sawn products, veneer, pulp, or chips. Under these restrictions, if a sale were offered and there were no bidders, the sale could then be reoffered without the primary manufacturing requirement. Poles and piling, structural timbers, and other products that would be used without further processing and that required no further manufacture were also exportable. With respect to Bureau of Land Management timber,

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[1/] USDA Forest Service. Plan for requiring domestic primary manufacturing of logs from National Forest land in the Pacific Northwest. 1968.

shipment of such products outside the States of Washington, Oregon, or California required written approval of the Bureau. Sale contracts made before April 22, 1968, were not affected by the restrictions.

Washington National Forests were allocated 199 million board feet of export quota

The export allocations to National Forest areas in Washington were as follows:

National Forest	Annual exportable log volume (Million bd. ft., Scribner long log scale)
Mount Baker	45
Snoqualmie	59
Olympic[1/]	30
Gifford Pinchot	55
Wenatchee[2/]	10
Total	199

1/ Restriction did not apply to either the Grays Harbor Federal Sustained-Yield Unit or the Shelton Cooperative Sustained-Yield Unit, both of which are located on the Olympic National Forest.

2/ Applied only to the Forest's west-side Ranger Districts, i.e., Cle Elum and Lake Wenatchee Ranger Districts.

Oregon Federal lands were allocated 151 million board feet of export quota: 91 on National Forests, 60 on BLM Districts

In Oregon both the Forest Service and the Bureau of Land Management had volumes exempted from the primary manufacturing requirements. The areas and allocations in western Oregon were as follows:

National Forest or District	Annual exportable log volume (Million bd. ft., Scribner long log scale)
National Forests:	
Mount Hood	51
Willamette	20
Siuslaw	10
Umpqua	2
Siskiyou	3
Rogue River	1
Deschutes[1/]	5
Total, National Forests	91

Bureau of Land Management Districts:	
Salem	14
Eugene	9
Coos Bay	12
Roseburg	10
Medford	15
Total, Districts	60
Total Oregon	151

1/ Applied only to the Forest's west-side Ranger Districts, i.e., Sisters, Bend, and Crescent Ranger Districts.

This log export restriction was superseded on January 1, 1969, by part IV of the Foreign Assistance Act of 1968 (Morse Amendment).

FOREIGN ASSISTANCE ACT OF 1968

Export quota of 350 million board feet extended through 1971

Part IV of the Foreign Assistance Act of 1968 (Morse Amendment) specifies that not more than 350 million board feet of unprocessed timber can be sold annually from Federal lands located west of the 100th meridian (a line running through the middle of North Dakota in the north and Texas in the south) for export from the United States.2/ This limitation is effective for each of the calendar years 1969 through 1971. The amendment covers all advertised sales with an appraised value over $2,000 and, as it is effective for the life of the timber sale contract, will not necessarily expire on December 31, 1971.

The amendment also applies to timber sale contracts which are extended at the request of the purchaser. This is true only on contracts made prior to the April 16, 1968, determination in western Washington and western Oregon, or contracts which were made prior to the effective date of the Foreign Assistance Act of 1968 (January 1, 1969) elsewhere west of the 100th meridian.

The 350 million board feet of exportable timber has been allocated 290 million board feet to the Forest Service and 60 million board feet to the Bureau of Land Management for calendar year 1969.3/ The portion of exempt volume to be allocated between the Forest Service and the Bureau of Land Management, and to each of the National Forests and BLM Districts, is subject to change in 1970 and 1971; however, the total exemption, 350 million board feet, will remain unchanged through 1971 unless specific quantities and species of unprocessed timber are declared surplus to domestic needs.

2/ U.S. Congress. Foreign assistance act of 1968 (P.L. 90-554, H.R. 15263), pt. IV. 1968.

3/ USDA Forest Service. Interim plan for implementing export restrictions of unprocessed timber from National Forests located west of the 100th meridian. 1968.

The restriction defines processed timber as:

1. Lumber and construction timbers, regardless of size, manufactured according to standards and specifications suitable for end product use

2. Chips, pulp and pulp products (in Alaska, which does not presently share in the exempted volume, only chips from milling and logging wastes will be considered to have received primary manufacture and will be exportable only if there is no economic market for this material in Alaska.)

3. Green veneer and plywood

4. Poles and piling cut or treated for use as such

5. Cants sawn on two sides, squares, and lumber cut for remanufacture of a nominal 8 inches in thickness or less.

This act also authorizes the Secretaries of the Departments of Agriculture and Interior to issue regulations preventing the substitution of timber restricted from export for exported non-Federal timber. On September 26, 1969, a joint Forest Service-Bureau of Land Management public advisory hearing on implementation of the substitution provision was held in Portland, Oregon. No regulations on substitution have, as yet, been issued.

Forest Service sales receiving no bids are treated differently in this regulation as compared with that of April 22. The April 22 restriction allowed such sales to be reoffered without the primary manufacturing requirement. Under the new restriction, if a sale receives no bids, advisory hearings must be held to determine whether the timber in the sale is surplus to domestic needs before the export restriction can be removed. The Bureau of Land Management action plan to implement the log export restriction is silent with respect to the handling of no-bid sales.

As the Morse Amendment also covers logs designed for export from sustained-yield units, those logs fall under the regulations of the Foreign Assistance Act. Thus all logs exported to foreign lands from a sustained-yield unit are included in the 350 million board feet quota.

National Forest log export allocation is 187 million board feet in Washington, 88 million in Oregon, and 15 million in California

The Forest Service has allocated 275 million board feet to Region 6 (Oregon and Washington), primarily to National Forest lands west of the Cascade Mountains,

and 15 million board feet to Region 5 (California). The distribution of the exempt volume by National Forest is as follows:

State and National Forest	1969 exportable log volume (Million bd. ft., Scribner long log scale)
Washington:	
Mount Baker	35
Olympic	33
Snoqualmie	57
Wenatchee[1/]	9
Gifford Pinchot	53
Total	187
Oregon:	
Mount Hood	49
Willamette	19
Siuslaw	9
Deschutes[2/]	4
Umpqua	3
Siskiyou	3
Rogue River	1
Total	88
California:	
Eldorado	3.8
Klamath	.8
Shasta-Trinity	3.8
Six Rivers	5.8
Stanislaus	.4
Tahoe	.4
Total	15.0
Total	290.0

1/ Exempt volume applicable only to the Cle Elum, Ellensburg, and Lake Wenatchee Ranger Districts.

2/ Exempt volume applicable only to the Bend, Sisters, and Crescent Ranger Districts.

All logs sold in Regions 1, 2, 3, 4, and 10 which are also covered by the restriction must receive primary manufacture within the United States. The criteria used in allocating the 290 million board feet to the National Forests are the same as those used under the Secretaries' determination.

Bureau of Land Management allocates its exportable timber volume to western Oregon districts

The Bureau of Land Management has allocated its 60 million board feet to its five BLM districts in western Oregon on the basis of each district's allowable cut. The allocation is approximately the same as that of the Secretaries' determination (see tabulation on page 3). All other BLM timber west of the 100th meridian is subject to the restrictions relating to the export of unprocessed timber from the United States. The allocation of exempt BLM volume to specific sales differs slightly between the Secretaries' determination and the Morse Amendment. Under the amendment, exempt volume is allocated, on a percentage basis, only to sales in excess of 2 million board feet. The Oregon State Director for the Bureau may, however, approve volume exemptions in sales that are less than 2 million board feet in size or adjust exemption proportions in larger sales when species, grade, composition, or market conditions make such a course desirable.

Some cedar declared surplus and exportable in Washington, Oregon, California, and Alaska

Under provisions of the amendment, the Secretaries of Agriculture and Interior can hold hearings to establish whether specific quantities and species of unprocessed timber may be surplus to the needs of domestic users and processors and thus freely exported.

Public advisory hearings were held in Portland, Oregon, on December 6, 1968, to determine whether two species, Alaska yellow-cedar and Port-Orford-cedar, were to be considered surplus. As a result of these hearings, the two Secretaries removed primary manufacturing requirements from Alaska yellow-cedar in Washington, Oregon, and California National Forests and Bureau of Land Management lands. Port-Orford-cedar is also exempted from primary processing, with one restriction. Because arrow shaft manufacturers pointed out their need for small amounts of dead and down Port-Orford-cedar trees, sales containing Port-Orford-cedar and designated as "arrow wood sales" are not considered surplus.

The amount of the two cedar species exported from Washington, Oregon, and California Federal lands will be in addition to the 350 million board feet permitted for export under the Morse Amendment.

In Alaska, public advisory hearings were held in Juneau on December 3, 1968, and on May 5, 1969, to determine whether the two species in question, Alaska yellow-cedar and western redcedar, could be considered surplus to domestic needs. At the December hearing, one mill then being constructed reported that it would require approximately 20 million board feet of cedar a year, and on this basis these species were considered necessary for domestic needs and thus not exportable. However, the mill later decided it would use little or no cedar in its operations. At a second hearing on May 5, 1969, these two species were declared surplus to domestic needs. Any volume of these two species exported to foreign countries from Alaska will be in addition to the 350 million board feet permitted under the Foreign Assistance Act.

STATE OF OREGON RESTRICTION

Oregon requires primary processing within United States

The State of Oregon has limited the foreign export of State-, county-, or city-owned logs in round form since 1961. The regulation, which excludes Port-Orford-cedar, requires primary processing within the United States. The State law defines "primary processed" as "that stage of manufacture next beyond the log form of said timber."[4/] However, the State Forestry Department will issue a permit allowing log exports if no economic market for the logs can be found in the United States. The State requires anyone seeking a permit to have the timber in log form. This prevents bidding on a State sale with the idea of exporting the timber, because the bidder does not know if he can obtain an export permit before the logs are cut. Since State lands in Oregon contribute only a minor part of the total log supply, the restriction has had little apparent effect on the log export volume.

WASHINGTON STATE'S INITIATIVE 32

Export restriction defeated in Washington; presently no limitation on State logs

In the State of Washington, there are no export restrictions on timber owned or managed by the State. Voters defeated Initiative Measure No. 32, titled the "Washington State Log Conservation and Full Employment Act," on November 5, 1968.[5/] This act would have required primary manufacturing of all timber from State-owned lands to take place in the State of Washington, or within 15 miles of the State's borders. The measure defined primary processing as either making all longitudinal surfaces of a log flat by sawing or converting a substantial portion of a log into veneer or chips.

Although Initiative 32 was defeated, its proponents announced that further attempts would be made either through State legislative action or by future initiatives to limit the export of Washington State logs. However, no new proposal to restrict export of logs from State-owned lands was introduced into the 1969 legislature.

SMALL BUSINESS ADMINISTRATION'S SET-ASIDE PROGRAM

Small Business Act limits exports to 30 percent of set-aside sale volume

The set-aside program under the Small Business Act has had the effect of limiting log exports from some sales, although this was not an express purpose of

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[4/] State of Oregon. Oregon forest laws and administrative rules. Pp. 17-18. 1967.

[5/] State of Washington. Initiative measure No. 32 to the Legislature, 40th regular session. Filed Feb. 3, 1967.

that act.[6/] Originally the program was designed to aid small businesses in obtaining a share of available public timber by making local timber available to the smaller, nonintegrated sawmills. The size of the "small business" as defined in the program allows firms with 500 or less employees to bid on these special sales. These small business set-aside sales are set up at the request of small businesses in an area. To be eligible, a firm must guarantee that 70 percent of the Federal logs purchased under the set-aside program will be manufactured into lumber with either its own facilities or those of other domestic concerns that also qualify as small businesses. In Alaska, the requirement is 50 percent. The 20-percent difference is to allow for resale of the large portion of pulp logs found on most Alaska timber sales. Timber sold under the set-aside program is subject to the export limitations of the Morse Amendment.

During 1968 there were 87 set-aside sales made on the National Forests in Washington and Oregon, representing a total volume of 274.6 million board feet or an average of 3.2 million board feet per sale.

PRIMARY PROCESSING REQUIREMENTS OF SUSTAINED-YIELD UNITS

The sustained-yield units were set up under the Sustained-Yield Forest Act of 1944. When established, they were primarily concerned with domestic competition for timber, but they also restrict log exports. There are six active sustained-yield units in the Nation: one cooperative unit, the Shelton unit located in northwest Washington, and five Federal units located in the West.

Shelton Cooperative Sustained-Yield Unit requires local processing of a volume equal to 80 percent of unit timber

The Shelton Cooperative Sustained-Yield Unit, set up in 1946 through an agreement between the Forest Service and Simpson Timber Company, covers approximately 270,000 acres in Mason and Grays Harbor Counties of western Washington. This agreement requires the cooperator to maintain within a 10-mile radius of the Shelton-McCleary area sufficient primary manufacturing plant capacity to use as a minimum 80 percent of the forest products removed from the cooperating lands.

Primary processing is not specifically spelled out in the agreement between the Forest Service and the Simpson Timber Company. However, the following statement from the agreement specifies the conditions to be met: "as to convert the raw material of the forest to salable manufactured products economically and within a minimum of waste . . . into products for which they are best suited."[7/]

In 1968, 162.1 million board feet of logs were sold from the Shelton Sustained-Yield Unit by the Forest Service.

[6/] U.S. Congress. Small business act (72 Stat. 384), pt. 121, as amended. 1953.

[7/] USDA Forest Service. Shelton Cooperative Sustained-Yield Unit. P. 15, 1957.

Grays Harbor Federal Sustained-Yield Unit requires 100-percent local processing

The Grays Harbor Federal Sustained-Yield Unit was established in 1949 in western Washington on the Olympic National Forest in Grays Harbor County.[8/] Primary manufacturing of all logs from this unit must take place in an area which covers most of Grays Harbor County. For the purpose of this unit, primary manufacturing is defined as the production of rough green lumber containing the approximate percentages of the various dimensions of lumber usually produced by mills of comparable size in western Washington, rough green veneer, chips, and shingles and shakes of any marketable grade. Special products, such as poles and piling, are excluded from the primary manufacturing stipulations.

Any purchaser of National Forest timber from the unit who is unable to find an economic market within the Grays Harbor area may, upon establishing this fact to the satisfaction of the Regional Forester, receive special authorization to market such timber elsewhere.

In 1968, the Forest Service sold 59.9 million board feet of logs from the unit.

Lakeview Federal Sustained-Yield Unit prohibits export of logs

The Lakeview Federal Sustained-Yield Unit was established in 1950 and is located in the Lakeview Working Circle of the Fremont National Forest in Oregon. The provisions require all timber sold for commercial use from National Forest land in the unit to be manufactured within 6 miles of Lakeview or 3 miles of Paisley.

Special forest products such as poles, piling, and fuelwood are excluded from the manufacturing stipulations. Primary manufacturing is defined as:

> The cutting of logs in sawmills into rough green lumber containing the approximate percentages of the various dimensions of lumber usually produced by mills of comparable size in the sawmill industry of the ponderosa pine area of eastern Oregon; and in addition the expenditure of at least an average of 5 man-hours of work per thousand board feet of logs used, in remanufacturing, refinement or other processing beyond the rough green lumber stage. In other log-using plants, manufacture will be considered to have been accomplished when an equivalent degree of employment has been expended on the material used.[9/]

The primary manufacturing definition used by the unit is currently undergoing some investigation. The requirement calling for 5 man-hours of work per thousand

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8/ USDA Forest Service. Amended policy statement for the Grays Harbor Federal Sustained-Yield Unit. 1968.

9/ USDA Forest Service. Amended policy statement for the Lakeview Federal Sustained-Yield Unit. P. 2. 1957.

board feet of logs used was established in 1950, and because of technological advancements the primary manufacturing requirements for the unit will probably be rewritten soon.

The three other Federal sustained-yield units also have primary manufacturing requirements. The Big Valley Federal Sustained-Yield Unit on the Modoc National Forest in northeast California requires 80 percent local processing for its timber; the Flagstaff Federal Sustained-Yield Unit in Arizona requires 85 percent; and the Vallicitos Federal Sustained-Yield Unit on the Carson National Forest in New Mexico requires 100 percent of its timber to be processed within 1 mile of Vallicitos, N. Mex.

ACT OF APRIL 12, 1926, ON FEDERAL TIMBER IN ALASKA

In Alaska there are primary manufacturing requirements on National Forest, Bureau of Land Management, and State lands. Private holdings in Alaska account for only 5 percent of total commercial forest land and about 1 percent of all commercial sawtimber; therefore, most of the timber in the State falls under primary manufacturing restrictions.

Alaska Federal lands fall under two export restrictions, the Act of April 12, 1926, and the Morse Amendment to the Foreign Assistance Act of 1968. The Act of 1926 authorizes the secretaries of the departments administering Federal lands in Alaska to issue rules and regulations regarding the export of timber.10/

Alaska Federal lands prohibited from exporting logs to other 49 States as well as to foreign countries

Under the authorization of the 1926 act, the Department of Agriculture made the following ruling on exports from Alaska National Forests:

> Timber cut from the National Forests in Alaska may not be exported from the Territory of Alaska in the form of logs, cordwood, bolts, or other similar products necessitating primary manufacture elsewhere, without prior consent of the Regional Forester . . . .
>
> In determining whether consent will be given to the export of such products, consideration will be given, among other things, to whether such export will (1) permit a more complete utilization of material on areas being logged primarily for products for local manufacture, (2) prevent loss or serious deterioration of logs unsaleable locally because of an unforeseen loss of market, (3) permit the salvage of timber damaged by wind, insects, or fire, (4) bring into use a minor species of little importance to local industrial development, (5) provide material required to meet national emergencies or to meet urgent and unusual needs of the Nation.11/

10/ U.S. Congress. Act of April 12, 1926, exportation of timber (44 Stat. 242; 16 U.S.C. 616). 1926.

11/ Office of Federal Register. Code of Federal regulations, sec. 221.25, title 36.

This ruling not only limits foreign exports of National Forest timber as does the Morse Amendment, but also restricts shipments to the other 49 States.

Primary manufacture of timber from Alaska National Forests under this law is defined as the production of cants, slabs, or planks 8 inches or less in thickness through the sawn dimension.[12/] Poles and piling and other products needing no further processing, green veneer, and pulpable material processed to a point where the wood fibers have been separated may also be exported. Chips cannot be exported unless they are produced from logging or mill waste and no economic market for the material can be found in Alaska. A permit to export timber from Alaska covers individual shipments only and is not renewable.

The Bureau of Land Management has basically the same restrictions on its Alaska lands as does the Forest Service. Applications for the export of timber within the United States are handled individually and are forwarded to the Secretary of the Interior for a determination.

STATE OF ALASKA'S LOG EXPORT RESTRICTION

All log export is prohibited on State-controlled lands in Alaska

Log export limitations by the State of Alaska on lands under its management vary somewhat from Federal limitations. The State's policy is to manage its forests on a sustained-yield basis, to protect existing industry, to provide for the establishment of new industries, and to derive revenue from all timber resources.

Primary manufacturing restrictions on Alaska State lands [13/] require cants 12 inches and under to be slabbed on two sides and cants over 12 inches to be slabbed on four sides. Chips derived from logging and mill waste which do not have a local market may also be exported. With an application approved by the Commissioner of Natural Resources, limited quantities of all species except spruce and hemlock may be exported in the form of round logs for experimental purposes only. Spruce and hemlock logs may not be exported under any condition from State lands in Alaska.

BRITISH COLUMBIA LOG EXPORT RESTRICTIONS

Provincial restrictions require primary processing within British Columbia

The Province of British Columbia has, since the passage of the "Timber Manufacture Act," effective March 12, 1906, prevented the export of logs from lands

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[12/] USDA Forest Service. Export and primary manufacture policy, National Forests of Alaska. 1961.

[13/] State of Alaska. Policy statement on primary manufacture, sec. 406.104, "Timber sale regulations." 1968.

owned by the Crown to areas outside the Province.[14/] Restrictions were set up in British Columbia, as in Alaska, to encourage the development of a forest industry in the Province, and these restrictions have remained basically the same since 1906. Primary manufacture is required of all timber from provincial lands, including those areas in which the timber cutting rights have been alienated under various types of licenses and leases. Lands granted after March 12, 1906, also are included.

In British Columbia, over 93 percent of the 118 million commercial forest acres are covered by the provincial log export restriction. The only timber for which there is no export control by the Province is that from lands alienated by the Province prior to 1906 and from lands alienated by the Federal Government in what was the Railway Belt, which was administered by the Dominion until 1930.

The Lieutenant-Governor in Council, with the advice of the Export Advisory Committee when appropriate, may authorize the export of piling, poles, and other unmanufactured timber from the Province, as well as allow the export of logs, if the logs have been offered to three potential timber buyers and no sale made. However, the timber must already have been cut and in log form before being declared surplus; this prevents the cutting of timber with the objective of exporting it. The export Advisory Committee representing loggers, manufacturers, and exporters is so constructed as to insure there will be no export of raw wood material which could beneficially have received further processing within the Province.

The degree of primary processing required in British Columbia is really just an application of custom. The requirements for exporting lumber are limiting only in the amount of wane permitted. The wane requirements, except for one exception, are the same as those found in the Export R List Grading and Dressing Rules[15/] for No. 3 common lumber. The exception is that wane is permitted to any degree on dimension lumber less than 3 inches in thickness. Lumber not meeting wane requirements cannot be exported. Most of the lumber shipments from British Columbia are 4 by 4, 8 by 8, or 12 by 12 squares. Chips can be exported only after a permit, valid for a stated period, is obtained in the same manner as a log export permit.

Generally, most log exports are from Vancouver Island and the lower mainland coastal area, with little or no export from the interior or northern coast.

In 1966 and 1967, over 65 percent of the logs exported from British Columbia were from lands requiring primary manufacture, for which a waiver from the Lieutenant-Governor in Council and the British Columbia Log Export Advisory Committee had been obtained. In 1968, 47 percent of the exports were under permit. About 2 percent of the total log harvest in 1967 and 1968 was exported.

Dominion restriction supports Provincial primary processing requirement

In addition to provincial regulations, the Canadian Dominion Government also prohibits the exportation of logs. There is a certain judicial conflict here, but the two governing bodies have administratively agreed to cooperate. When the

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[14/] Province of British Columbia. Forest act. Pp. 1471-1544. 1968.

[15/] Published by the Pacific Lumber Inspection Bureau Inc., Seattle, Washington, 1951.

British Columbia Log Export Advisory Committee issues an export permit, the Canadian Government's Department of Trade and Commerce also issues one. If the log export restriction were repealed by the British Columbia Government, the Dominion Government restriction would still prevent log exportation, and, conversely, if the Dominion restriction were removed the Provincial restriction would still stand. The Dominion also has the authority to prohibit the export of logs from all lands not administered by the British Columbia Provincial Government including private lands. However, there have been very few cases where such authority has been exercised. The primary processing requirements and other details regarding log exports are the same under both governments.

Summary Comparison of Various Log Export Restrictions

Restriction	Dates effective	Area covered	General limitations	Exemptions	Definition of primary processing
Secretaries' determinations	April 22, 1968, to December 31, 1968[1/]	Western Washington, western Oregon	Foreign export of logs from Forest Service lands of western Washington and western Oregon in excess of 290 million bd. ft. annually and BLM timber from western Oregon in excess of 60 million bd. ft. outside Washington, Oregon, and California	Port-Orford-cedar	Cants and squares 8 inches or less in thickness, poles, veneer, pulp, or chips
Morse Amendment to Foreign Assistance Act of 1968	January 1, 1969, to December 31, 1971	All areas west of 100th meridian	Foreign export of logs from Federal lands west of 100th meridian in excess of 350 million bd. ft. annually	Alaska yellow-cedar and Port-Orford-cedar in Washington, Oregon, and California; Alaska yellow-cedar and western redcedar in Alaska	Cants and squares 8 inches or less in thickness, poles, lumber, veneer, pulp, or chips (except Alaska chips)
State of Oregon lands	1961	Oregon	Foreign export of State logs	None	Next stage of manufacture beyond log form
Washington Initiative 32	(2/)	Washington	Export of State logs to either foreign or domestic markets	None	Logs with all longitudinal surfaces sawn flat, veneer, and chips
Small Business Administration's Set-Aside Sales	July 18, 1958	Decided or agreed to on a sale-by-sale basis	Processing of logs by other than U.S. small business firms	30 percent of the volume each sale (50 percent in Alaska)	Logs manufactured into lumber and timbers
Sustained-Yield Units: Shelton Cooperative	January 1, 1947, to December 31, 2046	Area within a 10-mile radius of the towns of Shelton and McCleary	Must process in area covered; a volume equal to 80 percent of commercial timber harvested from unit	None	Logs converted into salable manufactured products for which they are best suited
Grays Harbor Federal	November 2, 1949	An area lying within Grays Harbor County	Export from area of 100 percent of commercial timber harvested	On a sale basis providing no economic market can be found in the area	Rough green lumber and veneer, chips, shingles, and shakes
Lakeview Federal	October 10, 1950	6-mile radius of Lakeview and 3-mile radius of Paisley	Export from area of 100 percent of commercial timber harvested	None	Logs converted into lumber with an average of 5 additional man-hours of work per thousand bd. ft. of logs used in remanufacturing or an equivalent degree of employment
Act of April 12, 1926, on Alaska Federal Log Exports: Forest Service lands	1926	Alaska	Foreign or domestic export of National Forest logs	On a case-by-case determination	Cants and squares 8 inches or less in thickness, poles, veneer, pulp, or chips produced from mill wastes
Bureau of Land Management lands	1926	Alaska	Foreign or domestic export of BLM logs		
Alaska State lands	1960	Alaska	Foreign or domestic export of State logs	None	Cants 12 inches or less, slabbed on two sides, cants over 12 inches slabbed on four sides, chips from wood waste
British Columbia (Forest Act)	1906	British Columbia	Export of logs from the Province	By permit	Limited only in quantity of wane allowed (varies by size)

1/ These determinations were superseded on January 1, 1969, by the Morse Amendment; originally the determinations were to be effective until July 1, 1969.

2/ Never enacted.

Austin, John W.
1969. Log export restrictions of the Western States and British Columbia. USDA Forest Serv. Res. Pap. PNW-91, 13 pp. Pacific Northwest Forest & Range Experiment Station, Portland, Oregon.

Presents the main provisions of the log export restrictions and primary manufacturing requirements for timber products of the Western States and British Columbia.

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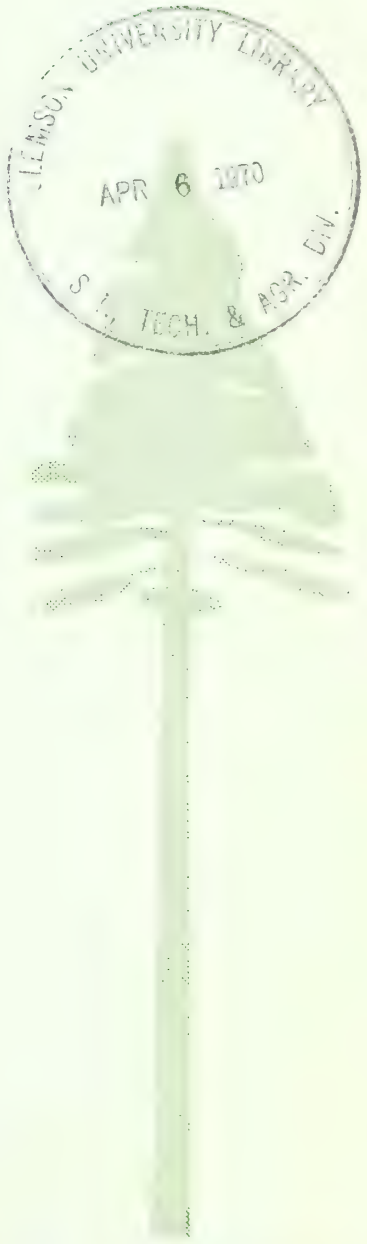

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STUMPAGE PRICE RESPONSES TO CHANGES IN VOLUME OF TIMBER SOLD

BY THOMAS E. HAMILTON

ACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION
OREST SERVICE · U.S. DEPARTMENT OF AGRICULTURE

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INTRODUCTION

The level of stumpage prices in relation to the quantity of National Forest timber sold is important in formulating timber sale policies.

The purpose of this report is to determine the effect on stumpage prices of changes in quantities of timber made available for harvest on the National Forests of western Washington and western Oregon.

If this relationship is known, the probable returns from alternative timber sale programs can be estimated and incorporated into the decisionmaking process. We will examine the 19-year period 1950-68.

LONG-TERM PRICE TRENDS

For perspective on the general level of stumpage prices, long-term demand, supply, and price trends will be examined first. We will then look more closely at National Forest price-quantity relationships.

Log Consumption in the Douglas-fir Region

Log consumption in the region has shown a long-term increasing trend since 1950 (table 1). Plywood and pulp production and log exports contributed to the trend (table 2). The production of plywood in Washington and Oregon was more than four times greater in 1968 than in 1950, an increase from 2.4 billion square feet in 1950 to 10.4 billion square feet in 1968. Pulp production increased almost two and one-half times during this period, from 2.4 million tons in 1951 to 5.9 million tons in 1968. During the 1950's, the volume of logs exported from the Douglas-fir region was negligible; but in 1961, log exports – mostly to Japan – became important. Since that time, the export volume has grown steadily to a level of 2.0 billion board feet in 1968. These increases in log consumption for plywood, pulp, and log exports have more than offset decreased consumption in the lumber industry, where production fell from 10.1 billion board feet in 1950 to 8.8 billion board feet in 1968, a 13.7-percent decline. Altogether, apparent log consumption for these uses rose 37.3 percent during this period, from 10.9 billion board feet, Scribner log scale, in 1950 to 15.0 billion board feet in 1968 (table 1).

Regional Timber Supply

The available timber supply from Douglas-fir region National Forests (allowable cut) increased 68.4 percent from 1950 to 1968; in 1950 annual allowable cut was 1.9 billion board feet and in 1968 the allowable cut was 3.2 billion board feet.[1] Comparable information is not available for all ownerships in the region, most notably for private lands; however, timber harvest information gives a reasonable indication of timber supplies made available over the 1950-68 time period. Total volume of timber harvested from all ownerships was 10.8 billion board feet in 1950; in 1968, total timber harvest was 13.6 billion board feet, up 25.9 percent from 1950 (table 3, fig. 1).[2]

---

[1] The main reasons for this increase are better and more intensive forest inventory, inclusion of smaller diameter trees to reflect changing utilization, a shorter conversion period, expectations for increased growth rates due to a larger number of smaller trees and more intensive forest management, a shorter regeneration period, inclusion of intermediate cuts as part of the regulated allowable cut volume, and addition of lands which were formerly inaccessible for logging.

[2] Total log consumption and total timber harvest figures do not coincide because (1) timber harvest does not include log imports into the region and materials such as cull logs; (2) part of the private timber harvest volume is estimated; (3) general conversion factors do not take account of species and log size variations; and (4) minor products are excluded from the log consumption figure.

Table 1.—*Apparent log consumption in western Washington and western Oregon, by major uses, 1950-68*

Year	Sawtimber		Pulpwood[1]	Log exports[2]	Total
	Lumber	Plywood			
	Million board feet, Scribner scale				
1950	8,073	1,023	1,850[3]	–	10,946
1951	7,871	1,129	1,812	–	10,812
1952	8,281	1,163	1,850[3]	–	11,294
1953	7,786	1,392	1,850[3]	–	11,028
1954	7,402	1,467	1,850[3]	–	10,719
1955	7,710	1,908	1,850[3]	–	11,468
1956	6,977	1,955	1,878	–	10,810
1957	6,334	2,040	1,768	–	10,142
1958	6,722	2,377	1,416	–	10,515
1959	7,243	2,876	1,536	–	11,655
1960	6,437	2,838	1,616	–	10,891
1961	6,190	3,104	1,560	336	11,190
1962	6,417	3,469	1,594	311	11,791
1963	6,841	3,703	1,518	709	12,771
1964	7,092	4,213	1,495	835	13,635
1965	7,057	4,337	1,729	901	14,024
1966	6,662	4,251	1,678	1,109	13,700
1967	6,353	3,974	1,533	1,572	13,432
1968	6,963	4,488	1,609	1,974	15,034

Source: Western Wood Products Association (1966 and 1969), Northwest Pulp & Paper Association (1969), USDA Forest Service (1969).

[1] Roundwood only. Includes two mills located in eastern Washington and excludes one western Washington mill.

[2] Volume was negligible before 1961.

[3] Estimated; data not available.

Long-term changes in Douglas-fir region timber supply are primarily a result of shifts in the supply curve rather than movements along the curve.[3] For example, the changes in National Forest allowable cut came about through increased knowledge of present and future timber management and utilization rather than from direct price influence. The quantity of private timber supplied is more likely to be affected by price changes, although any such effect would be more important in the short run.

[3] A timber supply curve is a schedule showing quantities of timber that will be offered on the market at different prices during a given time period. With a change in time period, factors such as technology, management, and utilization may cause a change in the quantities offered at these prices; this represents a shift in the supply curve (see fig. 5, p. 8).

Average Stumpage Price Trend

Stumpage prices have also shown a long-term increasing trend since 1950, although they have fluctuated considerably from

Table 2.—*Lumber, plywood, and pulp production and log exports from western Washington and western Oregon, 1950-68*

Year	Lumber production	Plywood production	Pulp production[1]	Log exports[2]
	Million board feet	*Million square feet*	*Thousand tons*	*Million board feet, Scribner scale*
1950	10,091	2,378	—	—
1951	9,839	2,625	2,439	—
1952	10,351	2,705	—	—
1953	9,733	3,238	—	—
1954	9,252	3,412	—	—
1955	9,638	4,437	—	—
1956	8,721	4,546	3,173	—
1957	7,918	4,744	3,402	—
1958	8,403	5,527	3,357	—
1959	9,054	6,688	3,511	—
1960	8,046	6,600	3,712	—
1961	7,738	7,218	3,668	336
1962	8,021	8,067	3,891	311
1963	8,551	8,611	4,045	709
1964	8,865	9,798	4,358	835
1965	8,821	10,086	4,956	901
1966	8,327	9,885	5,401	1,109
1967	7,941	9,241	5,536	1,572
1968	8,704	10,438	5,903	1,974

Source: Western Wood Products Association (1966 and 1969), Northwest Pulp & Paper Association (1969), USDA Forest Service (1969).

[1] Data not available for 1950 and 1952-55. Includes two mills located in eastern Washington and excludes one western Washington mill.

[2] Volume was negligible before 1961.

year to year (fig. 2).[4] Part of this increase can be attributed to demand for additional logs; in earlier years for rising plywood production, and more recently for log export. In addition, logs have attained a greater value through more complete utilization. The entire increase in volume of pulpwood used in the region from 1950-66 has come through use of chips and residue. In 1951, 21.6 percent of total pulpwood consumption was chips and residue. In 1966, this source made up 67.9 percent of the total.

Finally, technological advances have decreased the cost of some other factors of production, leaving a larger proportion of total revenue for stumpage purchases. For example, from 1952 to 1964, worker productivity in the logging industry increased 69.6 percent, and productivity in the sawmill industry rose 49.8 percent (*11*).[5] Over

[4] Stumpage prices in this report are constant prices determined by dividing the current price in each year by the wholesale price index for all commodities (1957-59 = 100) for that year.

[5] Italic numbers in parentheses refer to Literature Cited, p. 20.

Table 3.—*Public and private timber harvest in western Washington and western Oregon, 1950-68*

Year	All ownerships	Total private	Total public	USDA Forest Service
		Million board feet, Scribner scale		
1950	10,759	7,929	2,830	1,336
1951	11,540	8,699	2,841	1,429
1952	12,248	9,367	2,881	1,553
1953	11,033	7,970	3,063	1,778
1954	10,753	7,520	3,233	1,898
1955	12,096	8,601	3,495	1,903
1956	11,981	8,546	3,435	1,939
1957	9,495	6,426	3,069	1,744
1958	9,319	5,861	3,458	2,248
1959	11,186	6,555	4,631	3,176
1960	10,818	6,938	3,880	2,518
1961	9,659	5,661	3,998	2,544
1962	11,192	6,202	4,990	3,318
1963	11,604	5,942	5,662	3,452
1964	12,898	6,674	6,224	3,641
1965	13,012	6,785	6,227	3,887
1966	12,164	6,708	5,456	3,324
1967	11,489	6,424	5,065	3,198
1968	13,590	7,302	6,288	3,778

Source: USDA Forest Service (1951-69).

the same period, hourly wages in the logging industry rose only 26.6 percent and sawmill industry hourly wages were up only 38.6 percent (*12, 13, 14*).

Stumpage Price Expectations

Over a long period of time, stumpage prices are subject to different influences than affect them in the short term. In this section, prices will be examined to determine their expected future level in light of longer term influences.

Stumpage prices should show a continued upward trend in relation to the wholesale price index, with the greatest increase occurring within the next two decades. Projections for Japanese log requirements indicate an increasing need for imports until about 1985, after which time domestically grown timber will be able to support an increasing percentage of total wood needs in Japan (*2, 6*). Log exports are unique to the Douglas-fir region because of its location, and any increase in export demand should cause an upward pressure on stumpage price.

The recent restriction on log exports from Federal lands in Washington and Oregon may dampen the increase in log export volume, but lack of a complete export embargo should lessen the effect of this restriction. In addition, if efforts by the wood products industry to increase finished product exports are successful, the demand for stumpage will not decline.

Domestic demand for wood products is also projected to increase. There are a number of factors, however, which should

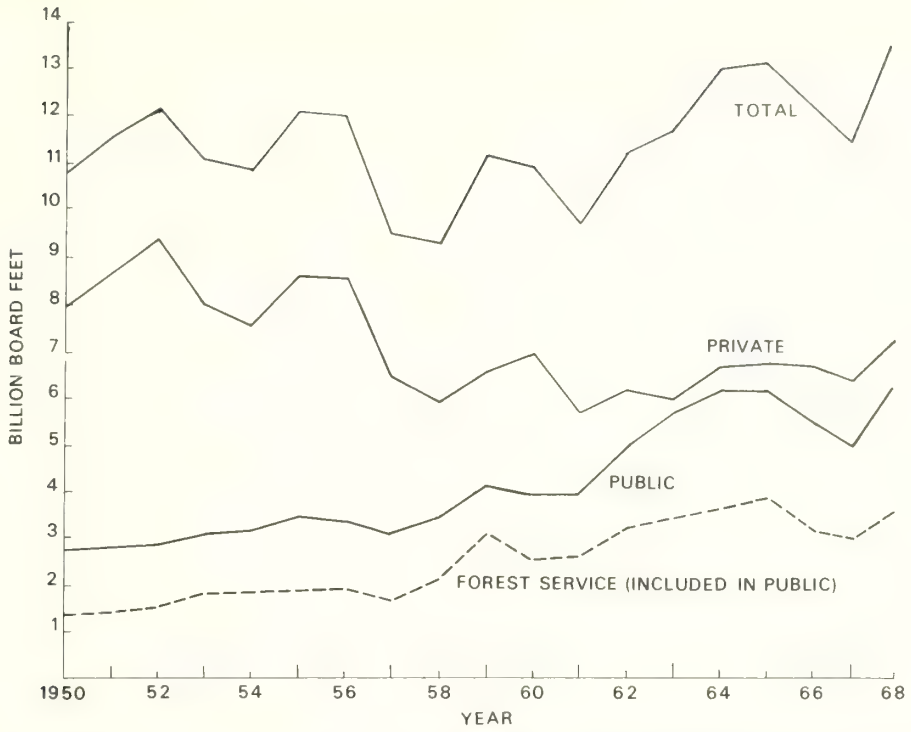

Figure 1.—Public and private timber harvest in western Washington and western Oregon, 1950-68.

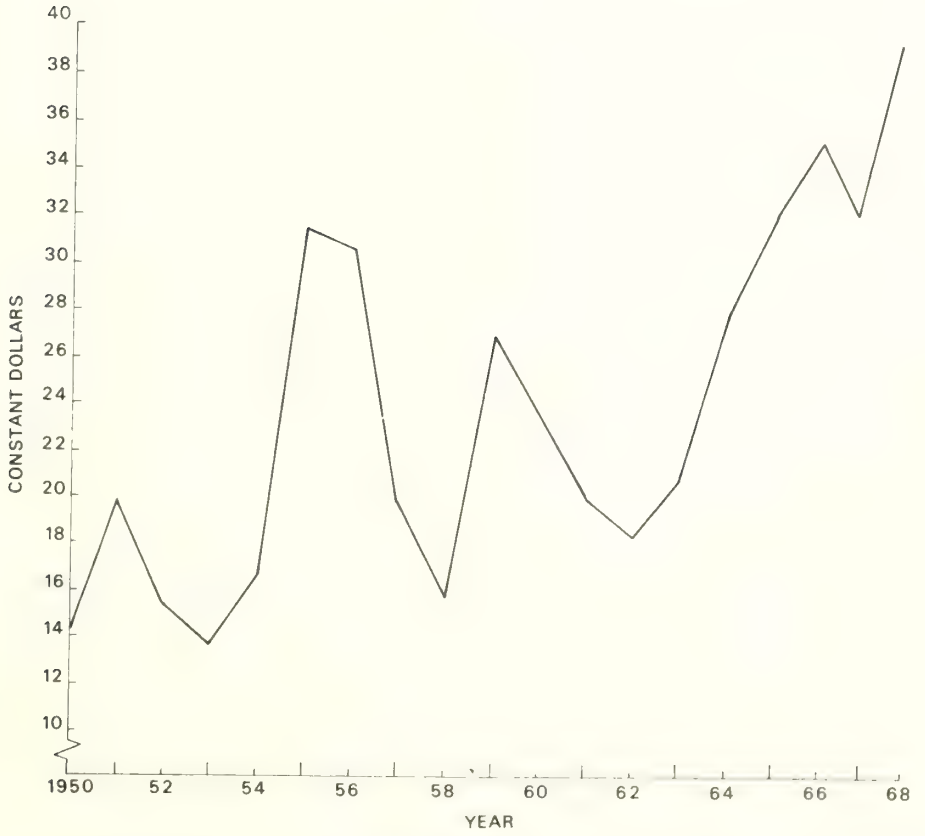

Figure 2.—Average annual stumpage prices for all species, western Washington and western Oregon National Forests, 1950-68.

dampen the price effect of this increase in the Douglas-fir region. First, other regions in the United States are currently gaining in importance in the production of some major forest products, and to some extent this gain is at the expense of the Douglas-fir region. The most notable example of this transition in area of production is in the plywood industry. In 1963, no softwood plywood was produced in the Southern States; in 1968, there were 34 plywood plants in the South which accounted for almost 16 percent of total U.S. plywood production. In 1966, plywood production in Washington and Oregon fell for the first time since 1960. This decline continued in 1967; however, 1968 production rose to a level slightly above that in 1965.

Second, other regions in the United States, principally the Rocky Mountain region, contain some areas where the allowable cut is not being completely used.[6] An increase in domestic requirements for forest products, with its accompanying upward pressure on price, should make increased cutting in these areas economically feasible.

A comparison of available volumes of timber and costs of production in each area would be necessary to determine from where additional supplies might come. Those areas which have timber just beyond the margin of profitable production would be the first to enter the market.

Third, competition from Canada, particularly British Columbia, will continue to be important. At present, British Columbia supplies about 79 percent of our Atlantic coast cargo market. Any upward pressure on price should make this market even more attractive to the Canadians. It appears that additional supplies may become available from British Columbia. From 1963 to 1968, British Columbia's allowable cut increased by 16 percent. In addition, both public and private foresters in British Columbia estimate that through more intensive management and better utilization, the harvest level of 1968, which was 1.7 billion cubic feet, could be substantially increased.

Finally, traditional wood products should continue to receive competitive pressure from nonwood substitutes.

Factors affecting demand, such as new technology, population, and foreign demand, are less predictable for long time periods. In addition, during the 1950-67 period, lumber prices have shown a relatively level long-term trend, and plywood prices have been declining despite major technological advances in wood use and substantial population gains (fig. 3). The sharp increase in prices in 1968 demonstrates the effect of a large increase in demand for wood products over a short period of time. This increase should be dampened somewhat as the factors mentioned come into play. Without long-term increasing final-product prices, stumpage price increases are possible only through better utilization, increased plant efficiency, or development of new products.

SHORTRUN PRICE CHANGES

In the short run, economic theory suggests that prices for stumpage will rise when the amount of timber offered for sale decreases and fall when timber offerings increase. In the stumpage market, the demand curve is traditionally thought to be very inelastic (see fig. 4).

There have been few studies of the characteristics of demand for stumpage *per se*, although several studies have been made in attempts to define the price elasticity of demand for timber and wood products. These studies have resulted in little success in specifying demand elasticities (7).[7]

[6] The National Forests in Regions 2 and 4, which include Nevada, Utah, Colorado, Nebraska, South Dakota, Wyoming, and southern Idaho, sold an average of 70 percent of their allowable cut over the period 1962-67.

[7] Holland, Irving. Some factors affecting the consumption of lumber in the United States with emphasis on demand. 1955. (Unpublished doctoral dissertation on file at Univ. Calif., Berkeley.)

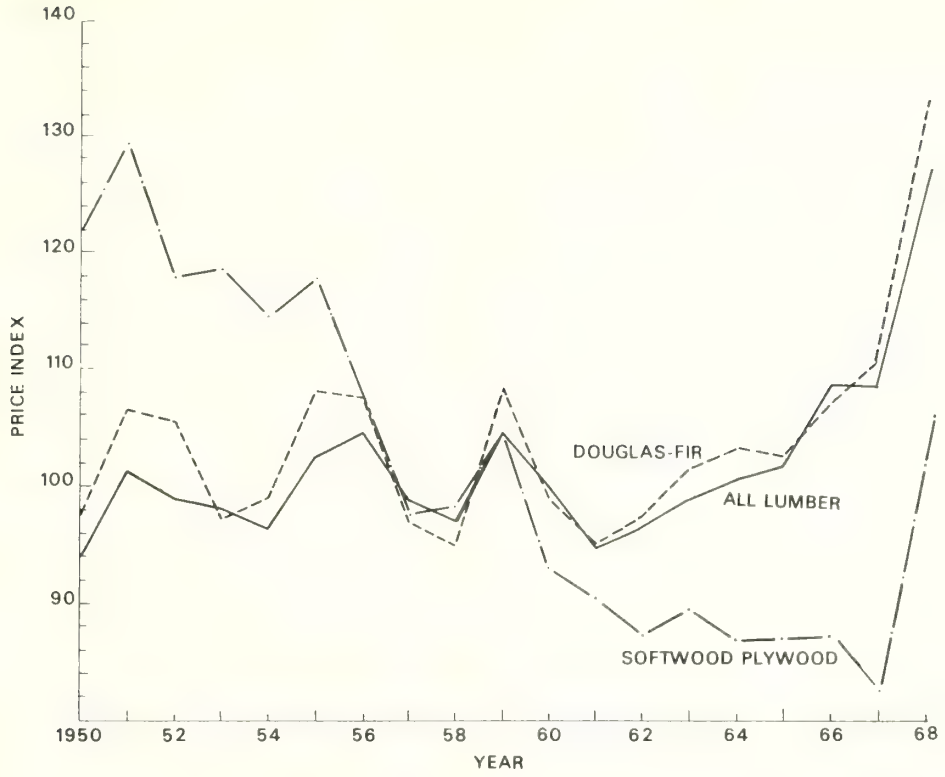

Figure 3.—Wholesale price indexes of lumber and softwood plywood, 1950-68 (1957-59 = 100). Source: U.S. Department of Labor, Bureau of Labor Statistics.

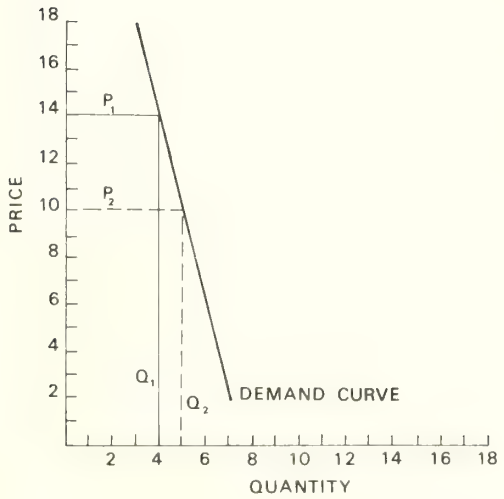

Figure 4.—An inelastic demand curve; a given percentage change of stumpage volume supplied (from Q_1 to Q_2) will be associated with a larger percentage change in stumpage price (from P_1 to P_2).

Nature of the Shortrun Regional Stumpage Demand Curve

The difficulty of specifying demand elasticities for wood products indicates that a universal statement on elasticity cannot be made. Instead, the variations in results of past studies suggest that each situation, even when similar products are considered, is unique and must be examined separately in light of its particular market characteristics.

In the Douglas-fir region, there is evidence to suggest that, except for extreme changes in stumpage availability, the demand curve for National Forest timber is highly elastic, taking the form shown in figure 5. Because of this, changes in the quantity of timber offered for sale under various harvest alternatives will have no appreciable effect on stumpage prices. This hypothesis is based on the following propositions.

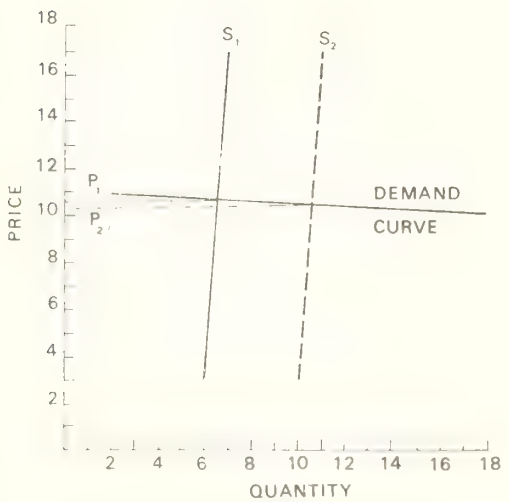

Figure 5.—An elastic demand curve; a shift from supply curve S_1 to supply curve S_2 will have little effect on stumpage prices.

Substitution.—Increased likelihood of substitution adds to the elasticity of demand for a product. As pointed out by Mead (*8*, p. 33), the greater the suitability and availability of substitutes, the greater the price elasticity of demand for a product. Since the demand for stumpage in the Douglas-fir region depends on the demand for finished products, we are interested in the availability of substitutes in both the stumpage and the final product market.

In the stumpage market, changes in the volume of logs sold on National Forest lands may bring about a response from private timberland owners. During the 1950-68 period, log production on private lands declined 7.9 percent from 7,929 million board feet to 7,302 million board feet. During the same period, timber harvest on National Forest lands more than doubled, from 1,336 million board feet in 1950 to 3,778 million board feet in 1968. The long-term decline on private lands has been attributed primarily to decreased private timber availability, rather than a response to increased public timber sales. However, during this period, fluctuations in private harvest were somewhat larger than were public fluctuations. Specifically, in periods when prices were high, private harvest was high and when prices were low, private harvest volume was low. It therefore appears that timber harvest on private lands is responsive to market conditions and that, if actions by public land managers increase or decrease available timber supplies and result in changed market conditions, these changes will be offset somewhat by private landowners' actions.

Changes in volume of Douglas-fir region National Forest timber sales may affect production in other regions. For example, areas in the Rocky Mountain region are not currently selling their entire allowable cut because the existing price-cost relationships make this material economically unavailable. Changes in log availability in the Douglas-fir region could increase or decrease the volume of timber cut in this area, thereby dampening any price change that might otherwise occur.

The effect of substitution is not limited to the stumpage market. In the consumer market, wood products and products made from other raw materials have frequently been interchanged, especially in the construction industry. A traditional concern in the forest products industry has been loss of markets to other materials. What is not usually considered, however, is the possibility that wood will recapture lost markets or move into new markets when the supply of timber is increased. This interchange between products should increase the demand elasticity in the consumer market and in the stumpage market.

Time.—The time period under consideration also affects demand elasticity. Generally, as the time period grows longer, more adjustments to a change in quantity supplied can be made and the effect of that change will be smaller. In this study, we are concerned with the effect on stumpage prices over a 1- or 2-year period following a change in annual timber sale volume on National Forests.

Obviously, time is important in the examination of substitution effects. An initial (large) change in volume of timber sold could have an immediate effect on regional prices. However, reactions to such changes appear to be rapid in the forest products industry (for example, private timber harvest fluctuated on a year-by-year basis, following general market conditions rather closely), and any price effect should be at least dampened somewhat by substitution effects.

In addition, time is important in evaluating the characteristics of the industry and stumpage market in the Douglas-fir region.

Industry and market characteristics.—Economic theory suggests that except under conditions of monopsony (a single buyer) or perfectly competitive sellers, the demand curve which an individual seller faces slopes downward to the right. Under this condition, a shift in either the demand or supply curve without a corresponding shift in the other will bring about a change in the equilibrium price.

In practice, only one situation exists where a shift in supply has no effect on price; this will happen when the supplier faces a perfectly elastic demand curve. Generally, when there is a large number of sellers, none of whom sell enough to influence price through individual supply action, the demand curve for each firm is perfectly elastic.

Mead (*8*, pp. 97-134) found that the market for lumber, which is national in scope, is unconcentrated, that barriers to entry into the lumber-producing business are relatively low, that products sold on the market are difficult to differentiate, and that lumber prices are market determined. This market condition is a close approximation of conditions under which perfect competition is found. We would therefore expect the demand curve facing individual firms in the lumber market to be very elastic (even though the total national demand curve may be much less elastic).

The same firms that sell lumber on the national market are the buyers of Federal timber on local markets. However, in the timber market, the number of firms competing for an individual sale is much smaller. Mead characterizes the buying side of this market as oligopsonistic; that is, few firms compete for timber sales in each timbershed.

Given this type of market structure, we would expect the demand curve facing timber sellers to be quite inelastic. However, several characteristics of the buying side of the stumpage market should reduce or negate any price effect which a change in supply might ordinarily have.

First, ease of entry into the buying side of the market means that firms must recognize potential entrants as well as existing firms when bidding for stumpage sales. Although stumpage prices have been found to be higher in areas where actual bidder numbers are high and lower where the number of actual bidders is low (*9*), we would expect the price differences to be even greater if the threat of future entry did not exist. In other words, the average stumpage price in areas where there are few

buyers is nearer to the price in more competitive areas than it would be if entry was difficult.

In addition, actual entry of new firms has a "self-correcting" effect on stumpage price changes resulting from changes in the quantity of supply. A hypothetical example of this effect is shown in figure 6. Assume that DD and SS represent the existing demand and supply curves for stumpage and P_1 represents the existing price. If an increase in volume of stumpage sold – a supply curve shift from SS to S'S' - causes a decline in stumpage price from P_1 to P_2 with no change in final product price, entry into the market should be induced. This would increase demand – a demand curve shift from DD to D'D' – forcing the stumpage price upward from P_2 to P_1. Although the long-term trend in number of mills has been downward during the 1950-66 period, the decline has slowed, or even reversed, during the periods of high product prices (*8*, pp. 118-119). The result has been a dampening of price fluctuations much the same as that which we would expect if supply changes induced an initial stumpage price change.

Second, the ability of the forest products industry to operate at less than capacity enables some adjustment to changes in timber supply and thereby reduces stumpage price changes. Fedkiw (*3*) found that the unused log input capacity of plywood and sawmills varied from 4.6 to 31.8 percent of total capacity over the period 1950-60 (capacity was defined as daily capacity listed by firms in the industry directory and includes one or more shifts as reported by each mill). Periods of high unused capacity during the 10-year span corresponded to periods of low stumpage prices and periods of low unused capacity coincided with those of high stumpage prices. In addition, annual fluctuations in total regional mill capacity, total regional log production, and stumpage prices were directly related in terms of highs and lows. Here it appears that demand rather than supply exerted the primary influence on stumpage prices. In addition, mills in the region can vary the degree to which their facilities are used according to market circumstances.

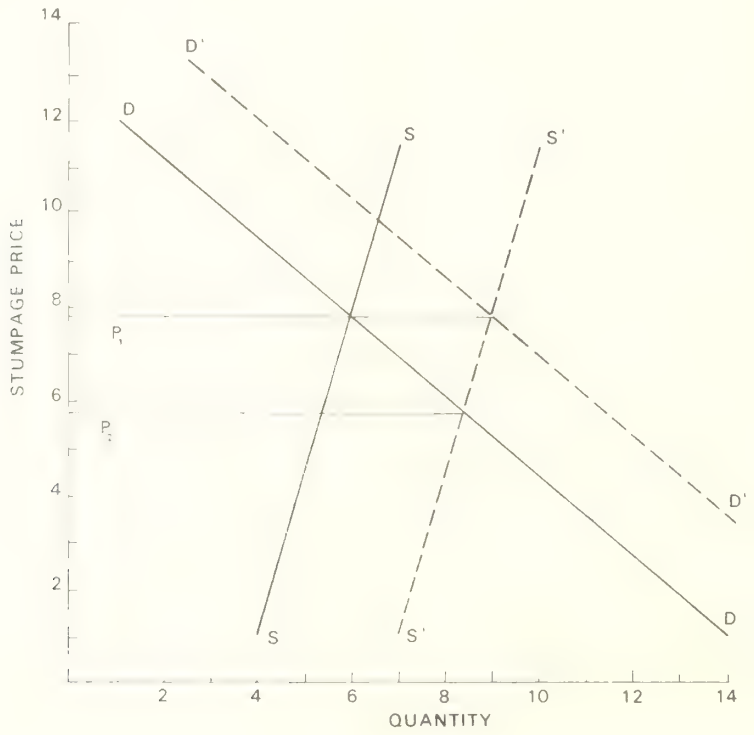

Figure 6.–The effect on price by entry of new firms as a result of a supply change.

This industry flexibility suggests, as we have hypothesized, that although overall stumpage demand may take the traditional downward sloping to the right form, within certain limits it is relatively elastic. Part of the reason for this may be reflected by the shape of the production function and stumpage demand curve for each forest-product firm.[8] Willingness of firms to operate at varying levels of output indicates that there may be little difference in productive efficiency at these different levels. In other words, the firm's production function has a range over which increased output per unit of additional input remains the same. Since an individual firm receives the same price for its product regardless of level of output, its total revenue curve would also increase at a constant rate per additional unit of input over this range. The demand curve for stumpage would take a form similar to that shown in figure 7. This curve shows the addition to total revenue from adding additional units of variable input. Over the range where increased output per unit of additional input is constant, the stumpage demand curve is horizontal. This horizontal (or elastic) portion of the demand curve may be relatively small for an individual firm; however, the cumulative effect of lumping all firms buying stumpage in a market area (fig. 8) could make productive flexibility an important factor in dampening price responses to changes in timber supply.

Public timber sale contracts are usually made for a period of 3 or more years. Because of this, timber buyers are able to hold a stumpage inventory of timber purchased but uncut. This inventory of uncut volume under contract in Washington and Oregon has been about twice the public timberland allowable cut over the past few years (*1, 5*). An increase in the volume of timber sold by public agencies could also be held as stumpage inventory while firms in the market are adjusting to the change. This ability to "store" timber on the stump would also tend to increase the elasticity of demand for stumpage.

Finally, the demand for stumpage is a derived demand; that is, it is dependent on the demand for products made from the stumpage. We would expect, as has been shown above, that fluctuations in prices for final products would produce similar price fluctuations in the stumpage market, and that high elasticity in final-product demand should produce high elasticity in the demand for stumpage. Since the demand for final products facing firms in individual timbersheds is very elastic, the demand for stumpage should also be elastic. One characteristic of derived demand is that its elasticity is usually less than the elasticity of the demand schedule from which it is derived. If, however, the deriving schedule has an infinite or nearly infinite elasticity, then the derived schedule should also be highly elastic.

Utilization.—Changes in the available volume of timber could also contribute to changes in degree of timber utilization. For example, a decline in physical timber supply could bring about use of material that might otherwise be left as logging residue. In addition, adoption of new technology in manufacturing (e.g., narrower saw kerf, thinner veneer) could enable output from a given log input to increase. Increased stumpage availability could have the opposite effect; that is, more material left in the woods or a slowdown in the rate of technological change.

Examples of this effect on utilization have been evident since the initiation of log exports. In recent years, a good deal of interest has been expressed in the chipping of currently unused materials. In addition, the operation of "chip-and-saw" mills, which can readily use small material, has been increasing.

Administrative regulation of logging or manufacturing practices could serve to offset or to emphasize utilization effects on prices. For example, requirements that loggers must remove all material to a given board-foot minimum would not allow substitution of additional stumpage sales

[8] A production function is a relationship describing the level of total production associated with each level of variable input such as the volume of lumber per 8-hour shift produced in a sawmill as related to number of workers employed.

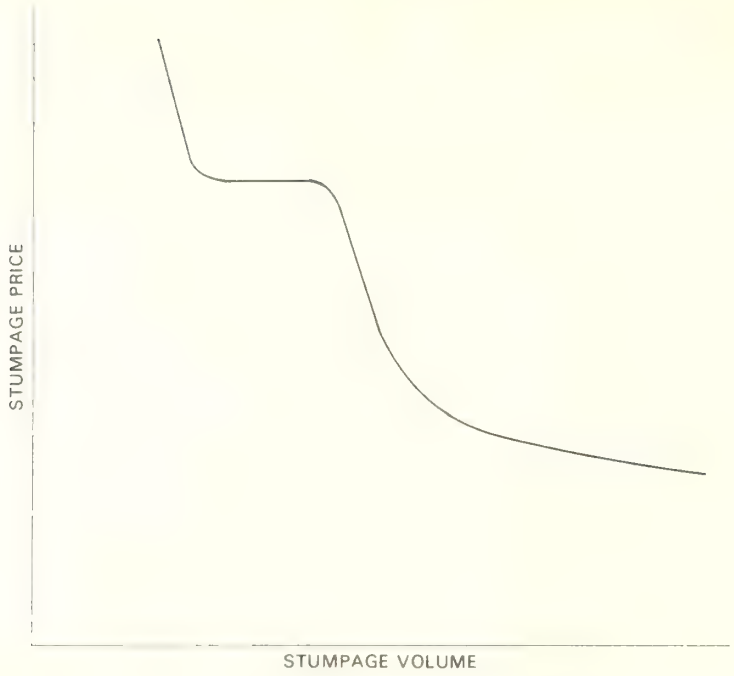

Figure 7.–A stumpage demand curve based on a production function with constant output per unit of additional input over part of its length and no variation in final product prices.

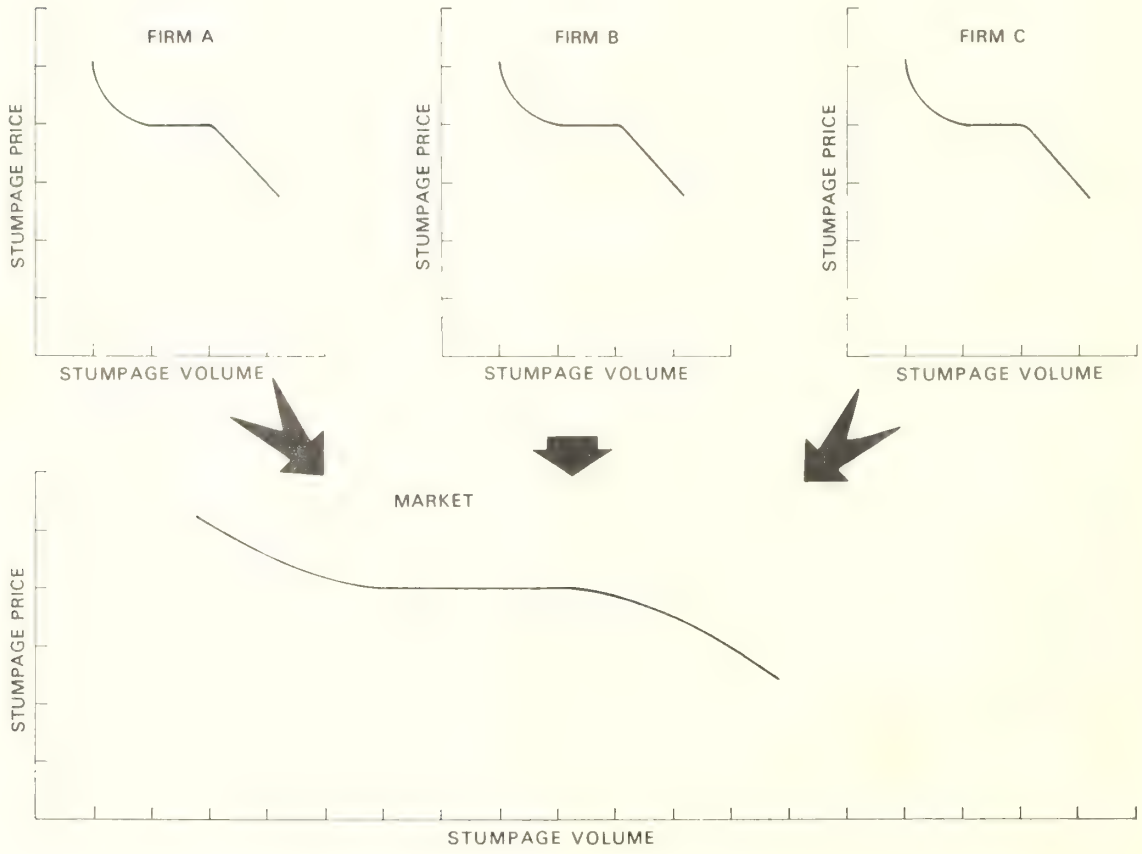

Figure 8.–An example of individual firm and market demand curves for stumpage.

for material that is more costly to remove on existing sales. Restrictions on the use of waste burners at manufacturing sites or slash burning in the woods would require alternative methods of residue disposal; some of these alternatives, such as chip manufacturing, would represent increased log utilization.

Relation of Stumpage Price Fluctuations to General Economic Fluctuations

To test our hypothesis, we will examine past shortrun stumpage price fluctuations with the accompanying changes in quantity demanded and supplied.

Figure 2 shows the all-species average annual Douglas-fir region stumpage prices from 1950-68. Although our long-term analysis showed an upward trend, there has been a good deal of fluctuation on a year-to-year basis. These fluctuations appear to be closely related to fluctuations in the general economy.

Figures 9, 10, 11, and 12 show four indicators of economic activity; U.S. gross national product, an index of common stock prices, rate of unemployment in the United States, and housing starts for the period 1950-68. The average stumpage price was at a low in 1954, 1958, and 1962. All four economic indicators declined or showed an appreciable slowing during or immediately before these years.

There are three primary reasons why the low points in these curves would not be expected to coincide. First, three of the statistics – housing starts, stock prices, and the unemployment rate – are leading indicators and would be expected to bottom slightly before the trough of a recessionary period. Second, the annual data do not allow precise pinpointing of the low point in aggregate economic activity. For example, the first recessionary period began in mid-1953 and ended in mid-1954, and the second lasted from mid-1957 to early 1958. The magnitude of the decline and recovery would therefore be important in determining the year in which the low value on the long-term annual trend fell. Finally, we would not expect any one variable to exactly fit aggregate fluctuations.

We will hypothesize that fluctuations in the general price level – characterized here by prices for wood products – have a positive influence on prices bid for National Forest stumpage. In other words, if prices paid for manufactured wood products are high, we would expect stumpage prices to be high; and if final-product prices are low, we would expect low stumpage prices.

It is difficult to directly relate prices bid for stumpage to final-product prices because of the wide and ever-changing variety of products and because the proportion of different species and grades sold each year varies.[9] However, the appraisal procedure used in setting a lower limit on stumpage prices is designed to take account of these variations. Although stumpage may not be used for the purpose for which it is appraised, the appraisal should represent a general pattern of final-product price changes.

In testing our hypothesis, we would expect the same relationship between bid and appraised prices as we would between bid and final-product prices; that is, bid prices should be high when appraised prices are high and low when appraisals are low.

In testing for correlation between bid and appraised prices over the period 1951-68, we obtain a coefficient of correlation of 0.87 and a coefficient of determination of 0.75, which means that 75 percent of the variation in bid prices may be explained by our measure of final-product price level, the appraised price. It therefore appears that final-product prices have a strong influence on the prices bid for stumpage.

[9] A comparison of figures 2 and 3 shows that shortrun peaks and troughs in the longrun stumpage and final-product price trends are roughly coincidental.

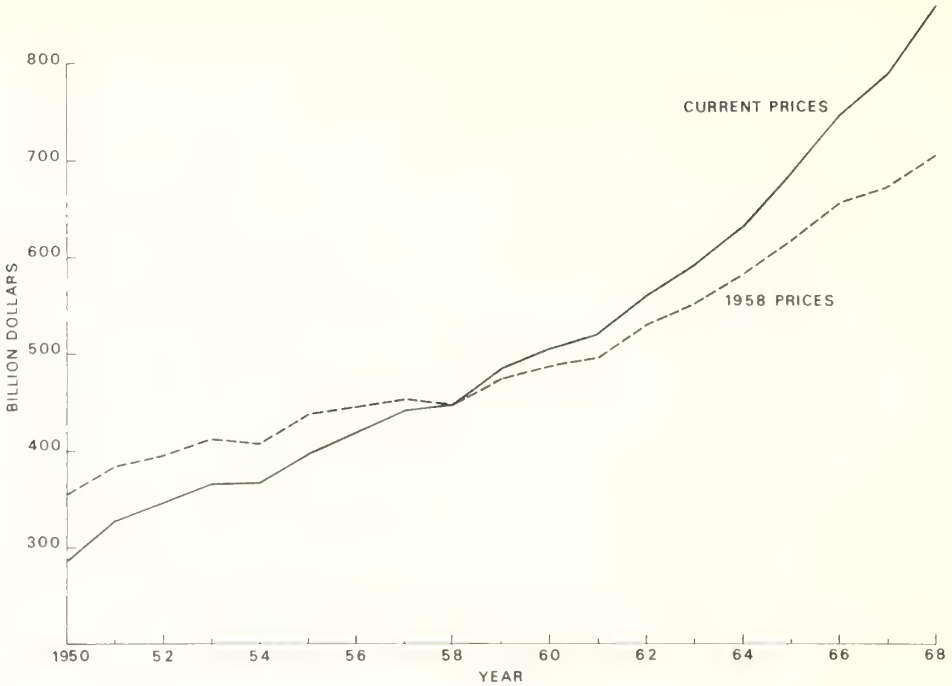

Figure 9.–United States gross national product, 1950-68.

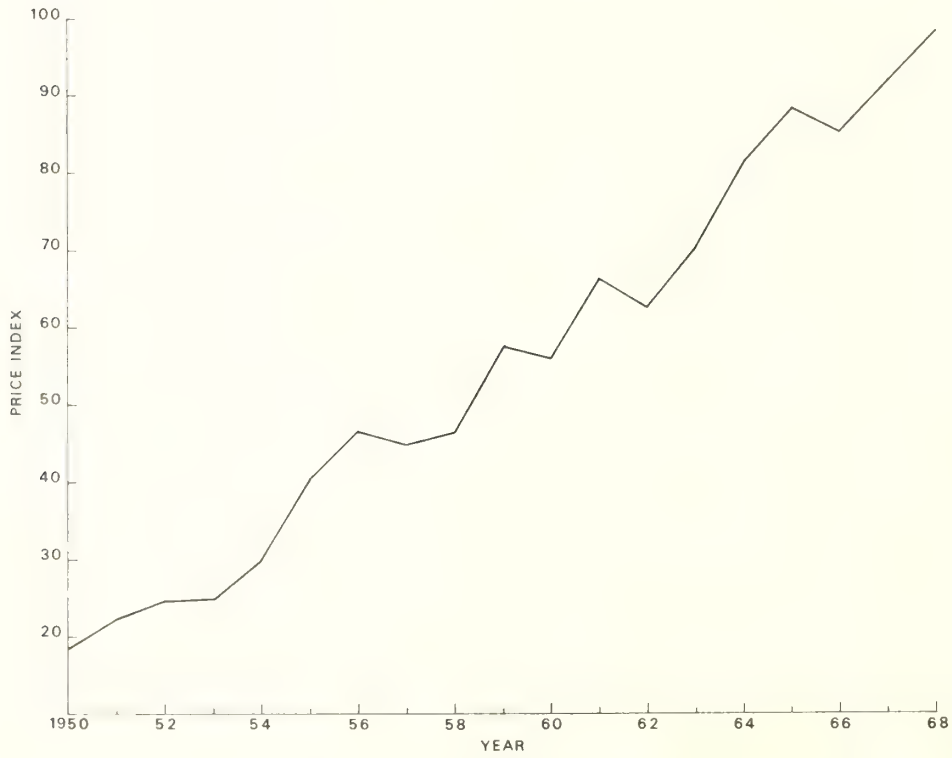

Figure 10.–Index of common stock prices, 1950-68 (1941-43 = 10).

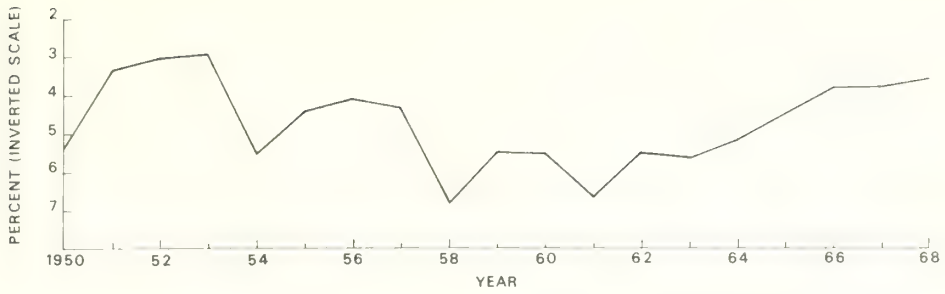

Figure 11.—U.S. unemployment rate, all workers, 1950-68.

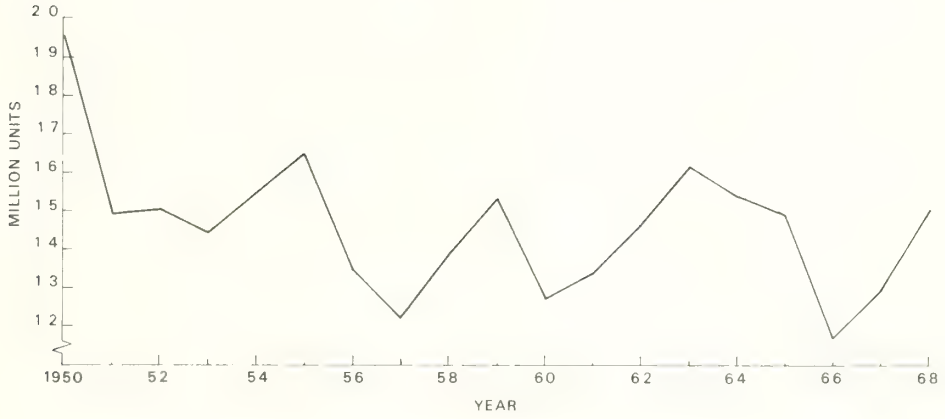

Figure 12.—Private and public, farm and nonfarm housing starts, 1950-68.

Further evidence of the effect of product prices can be seen in a comparison of the periods before and during the rapid rise in log export volume (table 4). Over the 13-year period 1951-63 when log exports were negligible, the ratio of bid to appraised price was 1.53:1, and bid prices exceeded appraisals by an average of $7.05 per thousand board feet. During the 5-year period 1964-68, bid prices averaged $11.58 more than appraisals and the bid-appraisal ratio was 1.84:1. Since log exports are not considered when appraisals are made, their effect should be like that observed — bid prices increasing at a much more rapid rate than appraisals.

Stumpage Price-Sale Volume Relationships

There is an imperfect year-by-year relationship between sale volume and allowable cut levels on National Forests. The allowable cut has increased steadily over the period we have been considering, the largest increase being 10.4 percent in 1957 (table 5). The only decline occurred in 1955 when allowable cut decreased 0.5 percent.

Since we are concerned with the price effects of changes in available timber supply, sale volume rather than allowable cut

Table 4.—*Volume and value of logs exported from Washington and Oregon, 1961-68*

Year	Volume	Value
	Million board feet, Scribner scale	*Dollars per thousand board feet*
1961	336	75.88
1962	311	69.65
1963	709	64.33
1964	835	67.98
1965	901	78.17
1966	1,109	82.84
1967	1,572	88.91
1968	1,974	102.37

Source: USDA Forest Service (1968).

Table 5.—*Allowable cut and volume sold on western Washington and western Oregon National Forests, 1951-68*

Year	Allowable cut		Volume sold	
	Volume	Change from previous year	Volume	Change from previous year
	Million board feet, Scribner scale	*Percent*	*Million board feet, Scribner scale*	*Percent*
1951	1,891		1,239	
1952	1,981	4.8	1,908	54.0
1953	2,020	2.0	1,368	-28.3
1954	2,187	8.3	1,860	36.0
1955	2,177	-.5	2,169	16.6
1956	2,272	4.4	2,233	3.0
1957	2,509	10.4	2,052	-8.1
1958	2,742	9.3	3,555	73.2
1959	2,783	1.5	3,140	-11.7
1960	2,815	1.1	3,085	-1.8
1961	2,822	.2	3,193	3.5
1962	2,988	5.9	3,041	-4.8
1963	2,988	–	4,306	41.6
1964	2,988	–	3,117	-27.6
1965	2,995	.2	3,191	2.4
1966	3,009	.5	3,450	8.1
1967	3,164	5.2	3,008	-12.8
1968	3,194	.9	3,545	11.8

Source: USDA Forest Service (1951-69a and b).

is the important variable. Over the period 1951-68, the volume of Forest Service timber sold in the Douglas-fir region fluctuated much more widely than allowable cut; in 6 of the 18 years, changes in sale volume exceeded 25 percent. These fluctuations appear to be responses to industry needs; for example, changes in sale volume, when compared to housing start variations, coincide with or occur 1 year after trend changes in the level of housing starts.

With the large observed fluctuations in volume sold, we would expect to find corresponding fluctuations in stumpage price in the opposite direction. Four periods in which sale volume increased substantially were from 1951 to 1952, up 54 percent; from 1953 to 1955, up 58.6 percent; from 1957 to 1958, up 73.2 percent; and from 1962 to 1963, up 41.6 percent. In two of these periods, 1951-52 and 1957-58, the quantity increase was accompanied by a stumpage price decline. In the other two periods, the increases in sale volume were accompanied by stumpage price rises. Part of this behavior can be explained by the indicators of economic activity shown in figures 9 through 12. For example, the two periods in which stumpage price declined followed substantial decreases in the level of housing starts. When fluctuations in housing starts and stumpage prices are compared, the housing movements appear to lead prices by 1 year.

On the other hand, housing starts increased during the two periods in which stumpage prices rose, and these periods followed years when housing starts were either relatively stable or increasing.

Four periods of declining sale volume were: from 1952 to 1953, down 28.3 percent; from 1958 to 1959, down 11.7 percent; from 1963 to 1964, down 27.6 percent; and from 1966 to 1967, down 12.8 percent. In the first of these, both stumpage prices and housing starts showed a decline, but in the second and third periods, decreased sale volumes were accompanied by price rises. Both of these periods followed years when housing starts increased; and in the 1963-64 period, log exports were becoming a factor in stumpage price determination. In the 1966-67 period, which followed a sharp drop in housing starts, prices declined.

If sale volume changes and changes in stumpage price are related, this relationship is even less clear on a Forest rather than a regional basis. In table 6, the number of Douglas-fir region Forests experiencing sale volume and stumpage price increases and decreases for the years 1956-68 is shown.

Table 6.—*Number of Douglas-fir region National Forests showing sale volume and average stumpage price increases and decreases, 1956-68*

Year	Volume		Price	
	Increase	Decrease	Increase	Decrease
1956	5	5	5	5
1957	3	7	1	9
1958	10	0	0	10
1959	2	8	10	0
1960	4	6	1	9
1961	5	5	3	7
1962	5	5	1	9
1963	9	1	8	2
1964	1	9	9	1
1965	5	5	9	1
1966	6	4	8	2
1967	3	7	3	7
1968	8	2	10	0

The direction of stumpage price change is much more uniform than the direction of sale volume change. In every year except 1956 in at least seven of the 10 Forests, stumpage price changes were in the same direction. Sale volume changes were not as uniform in directional movement; there was a distinct upward or downward movement in volume sold in 7 of the 13 years examined. In addition, the widespread increase in sale volume in 1963 and the decline in 1964 were a result of the October 1962 windstorm. It therefore appears that on a Forest-by-Forest basis there has been little relation between changes in volume sold and changes in average stumpage prices. This does not mean that volume sold has no effect on average stumpage price. Instead, it merely lends support to the contention that demand rather than supply factors are the dominant variables in determining shortrun stumpage prices.

Price Effect of a Net Change in National Log Supply

Physical supply changes appear to have little effect on regional stumpage prices. What would be the magnitude of a region-wide National Forest log supply change in terms of national log production, and what might be the stumpage price effect assuming no other changes take place?

Table 7 compares Douglas-fir region National Forest log production with total U.S. apparent log consumption. Although the proportion produced on the Douglas-fir region National Forests has increased over the 1950-68 period, in 1968 the region's National Forests accounted for only 4.8 percent of the total.[10]

If we assume the demand for wood products in terms of stumpage is very inelastic – for convenience we will use -0.1 in calculating the effect of a quantity change in log supply – and also assume no change in competition from other areas, competition from nonwood-based products, utilization standards, response of other landowners in the region, and the market's structure, we can calculate the price change associated with a 50-percent increase in National Forest timber sales in the Douglas-fir region. A 50-percent increase would amount to approximately 315 million cubic feet or an increase in the national total of 2.4 percent. Since the percentage change in quantity divided by the elasticity will yield the percentage change in price, this quantity increase would result in a 24-percent decrease in stumpage price.

The percentage change in price would decline rapidly as more elastic demand is assumed. For example, a demand elasticity of -0.5 (still inelastic) associated with the quantity changes given above would indicate a 4.8-percent stumpage price decrease. If an elasticity coefficient greater than -1.0 were assumed, the price change would be smaller in percentage terms than the change in quantity.

If, in addition, we relax our assumption of no other changes, factors we have discussed earlier will take effect. Since the Douglas-fir region's National Forests now provide less than 5 percent of the total roundwood for the Nation, and since changes we are considering here would probably be an even smaller percent of the total, these factors should markedly dampen the price effect of the supply changes being considered here.

[10] The U.S. log consumption figures shown are for all log uses. If only saw-log and veneer log consumption is considered – which is the use of most of the logs produced in the Douglas-fir region – the percentage of total U.S. consumption produced in the region is higher. For example, in 1968, Douglas-fir region log production was 8.1 percent of total U.S. saw-log and veneer log consumption.

Table 7.—*Log production on western Washington and western Oregon National Forests and total U.S. log consumption, 1951-68*

Year	Western Washington and western Oregon National Forest log production[1]	Total U.S. log consumption[2]	National Forest production, percent of total U.S. consumption
	Million cubic feet		
1951	238	12,055	2.0
1952	259	11,845	2.2
1953	296	11,925	2.5
1954	316	11,830	2.7
1955	317	12,230	2.6
1956	323	12,490	2.6
1957	291	11,300	2.6
1958	375	11,215	3.3
1959	529	12,160	4.4
1960	420	11,360	3.7
1961	424	11,230	3.8
1962	553	11,590	4.8
1963	575	11,970	4.8
1964	607	12,640	4.8
1965	648	12,855	5.0
1966	554	13,005	4.3
1967	533	12,480	4.3
1968	630	13,040	4.8

[1]Calculated from log production reports, Pacific Northwest Forest and Range Experiment Station, USDA Forest Service, using a factor of 6 board feet per cubic foot.

[2]From Demand and Price Situation for Forest Products, 1968-69, U.S. Department of Agriculture Misc. Pub. 1086; data for 1966, 1967, and 1968 are preliminary estimates.

CONCLUSIONS

Average stumpage prices for timber sold on Douglas-fir region National Forests have shown a longrun increasing trend. This trend should continue throughout the 1970's but begin to level off after that time. Despite the upward trend, these prices have fluctuated a good deal on a year-to-year basis.

An examination of the market for the region's stumpage indicates that shifts in wood products demand, rather than changes in the quantity of stumpage offered for sale, are the primary determinants of short-run price fluctuations. These fluctuations have closely coincided with fluctuations in general economic activity. On the other hand, variations in National Forest timber sale volume did not prove to be good indicators of stumpage price changes.

The results of this study suggest that changes in the volume of National Forest timber offered for sale – unless such changes are extreme – will have little effect on the general level of stumpage prices in the Douglas-fir region. The characteristics of the stumpage market – competitive demand conditions, industry adjustment to change, and supply response from other landowners and other areas – are such that both inter- and intra-regional adjustments should dampen a large part of the effect a supply change might otherwise have.

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C. A. Gray

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THE SITUATION

As man's awareness and concern for his environment increase, the forest becomes more recognizable as a storehouse of vital renewable resources — water, wood, forage, recreation, and wildlife habitat. At the same time, in considering man's dependence on his environment, the need to manage these resources by the multiple use principle — in combinations that will best meet the needs of all the people — becomes more apparent. But the growing number of planning factors imposed by rapid change makes multiple use management increasingly complex. Now, more than at any previous time in conservation history, we need to understand how resources of the forest are influenced by planned management for given objectives. This paper considers the broad spectrum of management activities and the water-yielding characteristics of a small basin in central Oregon.

Perhaps nowhere in this rapidly changing Nation is change more readily apparent than in the Pacific Northwest. The situation is exemplified by Oregon's population which has spiraled from only 13,000 permanent settlers in 1850 to approximately 2,000,000 at present. Though half the present population lives in or near 20 principal commercial or industrial centers, and large volumes of water are withdrawn for domestic, industrial, and power production users, irrigation is the greatest consumptive use of water in Oregon *(13)*. From simple diversions by early settlers, irrigation agriculture now extends to more than 1,500,000 acres. A recent report by the Oregon State Water Resources Board *(12)* projects a population of 9,000,000 requiring irrigation of 13,700,000 acres 100 years from now.

In response to changes that have either taken place or are projected for the future, two trends are of special significance to forest land managers. These are:

1. Demands for water supplies to meet needs are increasing.
2. Demands for use and occupancy of forest lands for the other resources — wood, forage, recreation, and wildlife habitat — are also increasing.

Both trends are due to the same mounting pressures — expanding population and improving technology. Fortunately, through increasing general knowledge of the influence of land and vegetation treatments on hydrologic performance, we are beginning to understand that these increasing demands are not necessarily conflicting. Rather, there is an interacting character of good resource management which can be of benefit to watershed objectives. Except where prohibited by certain institutional arrangements for land management, such as National Parks and wilderness areas, management practices applied to other forest resources can gain reinforcement from their effect on water yield. This concept is reflected in recent activity of the U.S. Forest Service in bringing management to bear upon improvement of water yields on lands tributary to a water-short area *(17)*.

WHAT IS UNDERSTOOD

General knowledge that vegetation and vegetation management can have a profound influence on streamflow has existed in this country for more than half a century. The earliest study of manipulation of forest vegetation in the United States was the Wagon Wheel Gap experiment begun in Colorado in 1910. In this joint Forest Service-Weather Bureau study, all vegetation was cut, windrowed, and burned on a 200-acre watershed in the headwaters of the Rio Grande River. Then a natural cover of aspen sprouts, grasses, and herbaceous plants was allowed to establish. During 7 posttreatment years, an annual increase of 0.96 inch, or 16 percent of the pretreatment yield, was attributed to removal of vegetation. Most of the increase was accounted for during the spring peak period *(2)*.

A number of tests of forest treatment effects on water yields have been made since the Wagon Wheel Gap study designed to consider variations imposed by differing climate, soils, and vegetative types. These studies, ranging from North Carolina *(10)* and West Virginia *(14)* to Colorado *(7)* and California *(15)*, have yielded the general result that streamflow increases when forest density is decreased. Also, this effect is soon followed by a trend toward original or pretreatment flow values if regrowth is allowed *(11) (9)*. Bates *(1)*, a pioneer in watershed management, likely had the results of his Wagon Wheel Gap study in mind when he wrote, in part:

> Foresters, again and again, have pointed out the probability that a watershed bare of vegetation is capable of yielding a larger total quantity of water than the same watershed if covered with a forest, and the denser and more luxuriant the vegetation, the greater the loss of water to the watershed. This is a biological phenomenon no longer in need of proof.

Most investigators, however, see the role of forest vegetation as a paradox. Although there is evidence that forest stands can be modified to favor water yield, vegetation also plays a primary role in site stability and maintenance of water quality. Manipulations to reduce onsite water use should be applied only within limits which do not jeopardize the protective function.

Although studies of the relations between vegetation and water yields have provided intriguing prospects for resource management, there is feeling that the foundation is inadequate for widespread application *(4)*. The scale of the tests has necessarily been limited, and not all regional variations have been touched upon. Broader scale tests or operational demonstrations on the effects of cover manipulation on water yield are needed.

THE CASE OF OCHOCO CREEK

In order to fix vegetation-streamflow relations on forest lands tributary to water-short areas of Washington and Oregon east of the Cascade Range, a number of experiments are being undertaken. Pending completion of these studies, it is possible to gain some insight on the effects of forest management activities by using available hydrologic data and forest use records. This case study has been made in order to evaluate the hydrologic performance of Ochoco Creek above Ochoco Reservoir (cover photo) in central Oregon in light of the use history of forested lands comprising the bulk of drainage area.

Study Area

Total drainage area tributary to Ochoco Reservoir, 6 miles east of Prineville, Oreg., is about 295 square miles, or 189,000 acres (see frontispiece). Elevations range from 3,100 feet at the reservoir to nearly 7,000 feet at the headwaters. Mean elevation is 4,600 feet. Generally, topography is gentle (fig. 1), with some rugged terrain at the uppermost reaches. Landscape features are strongly influenced by geologic formations present. A deeply fractured Clarno Formation, considered late Eocene or early Oligocene in age and lacustrine fluviatile in origin, predominates. The eastern or upper portion of the drainage is covered by the younger lavas of the Columbia River Formation, mid-Miocene fissure flows of fine-grained basalts, and andesites. A mantle of volcanic ash or loess of varying thickness and texture overlies both formations.

Soils reflect the normal influence of such environmental factors as elevation, exposure, vegetation, and position, as well as localized influences from clay beds or ash layers

Figure 1.--Downstream view of Mill Creek, tributary to Ochoco Creek.

found in the Clarno Formation. Most of the lower elevations are characterized by shallow soils on relatively steep slopes with occasional large rock outcrops. Deep, gravelly, medium-textured soils are found in the valley fill and narrow flood plain positions in major stream systems. Deposits of strong, medium-textured soils are found on alluvial fans that issue from side drainages and overlap the valley fill. At middle elevations, slopes become more complex and give rise to a variety of landforms including benches, valley fills, hummocky slump areas, and moderately steep colluvial slopes. Small areas of medium- to fine-textured valley fills are interspersed throughout the upper reaches.

Climate approximates Köppen's cool, snow-forest type *(8)* characterized by abundant sunshine, high evaporation, and wide daily and monthly temperature ranges. Mean annual temperature is 43° F. The coldest and warmest months, respectively, are January when temperatures frequently fall below 0° F. and July when temperatures occasionally exceed 100° F. Freezing can occur during any month, but mean frost-free season is about 60 days near 3,000 feet elevation. Frequently, under summer conditions, humidity will drop to 10 percent during the day. With 60 percent or more of possible sunshine, potential evaporation exceeds 36 inches annually.

Mean annual precipitation for the watershed is about 25 inches, ranging from 10 inches at lower elevations to nearly 50 inches in the highest reaches. Most precipitation falls during the October-June cool season, with about 50 percent occurring as snowfall. Mean monthly precipitation and air temperature at selected stations are summarized in table 1.

Approximately 75 percent of the drainage has forest cover consisting primarily of a ponderosa pine type (fig. 2), with minor amounts of associated species (Douglas-fir, white fir, and western larch) and lodgepole pine. A small amount of alpine fir is found at the highest elevation. Most of the mature forest types have an understory of young trees varying in density from a few to over 10,000 stems per acre.

An herbaceous ground cover composed mainly of grasses and sedges occurs under most timber canopies. Deep duff and litter are found only under very dense firs.

Nonforest types make up the remaining 25 percent. Sagebrush *(Artemisia tridentata)* is the dominant cover in scattered locations at the highest elevations, and juniper *(Juniperus occidentalis)* is prevalent at the lower elevations *(5)*. Meadows, pastures, and irrigated farmlands occupy the valley fills.

Land Use History

Ochoco Reservoir, with a capacity of 47,500 acre-feet, was constructed primarily for irrigation purposes in 1920. The drainage area is 189,000 acres, of which 106,000 acres are administered by the Forest Service and 83,000 acres are in private ownership. Ochoco, Mill, and Marks Creeks are the major streams feeding the reservoir.

There are 52 established water rights, some dating back to the late 1800's, for irrigation of slightly more than 3,400 acres of land above the reservoir.[1] This acreage has remained essentially unchanged for many years, although rates and methods of water application may have varied among different landowners. The main irrigated crops are pasture, hay, and some small grain. The normal irrigation season, from April through August, requires about 4 acre-feet of water per acre.

There are no natural storage lakes in Ochoco Creek. Walton Lake, a manmade pond of about 20 surface acres near the headwaters, reached its present stage in 1958. Annual water retention to offset pond evaporation amounts to about 50 acre-feet.

One of the earliest uses of the watershed was mining for gold and cinnabar. Placer and hard-rock gold mining started around 1855, but mining operations since that time have been sporadic. About $80,000 in gold was produced *(6)*. There has been no recent gold mining activity. Cinnabar was discovered in 1899 in the vicinity of Lookout Mountain.

[1] Personal communication with Mr. Joe Cox, local watermaster for Oregon State Engineer's Office, June 23, 1969.

Table 1.--*Mean monthly precipitation and air temperature, Ochoco Creek Station*

Month	Precipitation				Mean air temperature	
	Prineville	Ochoco Dam	Ochoco Ranger Station	Marks Creek Guard Station	Prineville	Ochoco Ranger Station
	Inches				*Degrees Fahrenheit*	
October	0.78	0.79	1.65	1.57	48.1	45.5
November	1.10	1.14	2.48	3.77	39.7	34.4
December	1.04	1.27	2.75	3.75	33.3	28.7
January	.99	1.12	2.19	3.10	31.0	24.3
February	.84	.85	1.75	2.20	35.5	29.5
March	.66	.84	1.60	2.49	40.0	34.4
April	.70	.65	1.31	1.88	46.0	41.6
May	1.09	1.47	1.71	1.76	52.2	48.6
June	.99	1.00	1.68	1.46	57.8	53.8
July	.30	.31	.58	.78	64.5	61.4
August	.31	.46	.60	.77	62.6	59.7
September	.57	.40	.75	.73	56.0	55.2
Annual	9.37	10.30	19.05	24.26	47.2	43.1

NOTE: Elevation in feet is as follows--Prineville, 2,868; Ochoco Dam, 3,057; Ochoco Ranger Station, 3,979; Marks Creek Guard Station, 4,600.

Figure 2.--Mature ponderosa pine typical of many stands on Ochoco Creek.

Mining since that time has been sporadic with some activity as recently as the late 1950's and early 1960's *(3)*.

The earliest cinnabar mining was underground, but the more recent technique has been open pit mining. An area of about 20 acres of open strip mining work exists in the Lookout Mountain vicinity. Otherwise, there have been no significant land disturbances, clearings, or water use for mining since the construction of Ochoco Reservoir in 1920.

There has been recent prospecting for agates, jasper, and other semiprecious stones at scattered locations throughout the watershed. No significant land disturbances have resulted from this activity.

Grazing by cattle and sheep was another early use of the area. Unregulated grazing of large numbers was a common practice in the late 1800's and early 1900's. However, grazing records on National Forest land show grazing use by cattle or sheep to be quite stable since 1924, annually averaging about 933 and 3,100 animals, respectively. Normal season of use is from about June 1 to mid-September. Table 2 shows the permitted numbers of grazing stock on National Forest and certain private lands.

A resident mule deer population was estimated at 1,500 animals through 1950 and 5,000 in 1964. The watershed also supports a small, unestimated number of Rocky Mountain elk. Hunting is allowed and is one of the major recreational uses.

Other recreational use in the watershed is quite diversified. Fishing, "rock-hounding," camping, picnicking, sightseeing, hiking, and harvesting of forest products for pleasure are permitted and dispersed throughout the basin. Concentrated recreational use takes place mainly at Walton Lake Campground, Wildcat Campground, Ochoco Summit Campground, and White Rock Springs where formal facilities are established. Ochoco Reservoir is a very popular area for water-based recreation. Over 121,000 day visitors and 7,100 overnight campers used the facilities at Ochoco Lake State Park in 1967.

Timber harvesting, the major land use on Ochoco Creek, had a tentative beginning in the mid-1800's when early settlers cleared lands along the stream bottoms of Ochoco, Marks, and Mill Creeks for farming. However, commercial harvest of timber did not start until about 1938 and then was principally limited to private land in the lower reaches of the watershed. From 1938 through 1945, almost 150 million board feet of timber was removed from about 25,000 acres of private land. This was a heavy cut, intended to remove 75 percent of the standing volume, yielding 2,900 to 7,700 board feet per acre. Beginning in 1947, cutting practice on private land became one of sanitation salvage, generally relogging to remove about 1,900 board feet per acre.

Commercial timber harvesting on National Forest land did not begin until 1942. By 1950, more than 100 million board feet of timber had been removed from 14,000 acres. Per-acre cut, designed to remove 65 percent of merchantable volume, ranged from 3,500 to 12,000 board feet. Since 1950, large areas have been salvage logged of high risk timber, but generally small per-acre volumes are removed. This salvage operation has relogged much of the cutover land.

In total, over 400 million board feet of timber was harvested from the Ochoco Reservoir watershed between 1938 and 1965. Cutting on both private and Federal lands has been concentrated in the mature ponderosa pine type. As data on volumes removed per acre indicate, cutting practices have varied from essentially complete removal of mature overstory to a very selective removal of scattered trees throughout the stand (fig. 3). Timber volumes removed from the watershed are summarized in table 3.

Figure 3.--Mature ponderosa pine stand after logging.

Table 2.--*Grazing record in Ochoco area, 1924-65*

(Animal months[1])

Year	Cattle	Sheep	Year	Cattle	Sheep
1924	4,442	--	1948	3,690	11,330
1929	3,800	1,188	1949	3,557	12,748
1930	3,700	6,500	1950	3,537	12,079
1931	3,600	6,500	1951	3,589	12,553
1932	3,500	6,500	1952	3,557	14,653
1933	3,400	6,500	1953	3,557	14,509
1934	3,300	6,500	1954	3,557	13,709
1935	3,200	17,834	1955	3,557	14,013
1936	3,100	6,500	1956	3,644	14,810
1937	1,200	6,500	1957	3,644	14,236
1938	2,897	6,500	1958	3,661	13,345
1939	2,560	6,500	1959	3,679	10,635
1940	2,392	19,413	1960	3,516	15,380
1941	2,461	9,658	1961	3,177	14,835
1942	2,435	9,265	1962	3,278	10,105
1943	2,249	9,265	1963	3,466	9,571
1944	1,985	9,265	1964	3,624	14,995
1945	2,050	10,974	1965	4,192	10,662
1946	3,690	--	Total	124,133	379,530
1947	3,690	--	Average	3,267	10,844

[1] Animal month = one mature cow with calf or one ewe with lamb for a month's tenure.

Because cutover areas either supported advance reproduction initially or reserve stands ensured regeneration, second-growth stands contained maximum numbers of vigorous stems (fig. 4). Beginning in 1955 on some of the areas first logged, a precommercial thinning program was initiated in dense ponderosa pine stands ranging from 2 to 8 inches in diameter. The thinnings, designed on the bases of site index and size class, have resulted in spacings of 10 to 14 feet between crop trees. A total of 1,410 acres were treated in this manner during the period 1955-65.

There are nearly 300 miles of roads, varying from two-lane asphalt highways to narrow, unsurfaced work roads in the watershed. Most, however, are rock-surfaced access roads (fig. 5) progressively built in connection with timber harvesting. It is estimated that these roads comprise a total of 500 to 600 acres of bare surface.

Table 3.--*Annual timber harvest record, Ochoco Creek, 1938-65*

Year	Cut Volume		Area logged		Average volume cut per acre	
	Private[1]	Forest Service	Private[1]	Forest Service	Private[1]	Forest Service
	Thousand board feet		*Acres*		*Board feet*	
1938	18,500	0	2,400	0	7,700	--
1939	18,500	0	2,400	0	7,700	--
1940	18,500	0	2,400	0	7,700	--
1941	18,500	0	2,400	0	7,700	--
1942	18,500	2,711	3,240	220	5,700	12,300
1943	18,500	250	6,427	21	2,900	11,900
1944	18,500	708	3,593	59	5,140	12,000
1945	18,500	727	2,604	61	7,100	11,900
1946	2,000	7,964	453	664	4,410	12,000
1947	4,800	13,916	2,500	4,011	1,900	3,500
1948	4,800	12,460	2,500	1,577	1,900	7,900
1949	4,800	35,421	2,500	4,800	1,900	7,400
1950	4,800	27,228	2,500	3,230	1,900	8,400
1951	4,800	512	2,500	50	1,900	10,000
1952	4,800	2,803	2,500	9,080	1,900	300
1953	4,800	531	2,500	106	1,900	5,000
1954	4,800	3,661	2,500	8,500	1,900	430
1955	4,800	0	2,500	0	1,900	--
1956	4,800	488	2,500	6,100	1,900	80
1957	4,800	1,849	2,500	217	1,900	8,500
1958	4,800	11,544	2,500	17,240	1,900	660
1959	4,800	4,349	2,500	765	1,900	5,700
1960	4,800	9,384	2,500	13,795	1,900	680
1961	4,800	3,524	2,500	7,160	1,900	490
1962	4,800	462	2,500	400	1,900	1,150
1963	4,800	31,170	2,500	10,628	1,900	2,900
1964	4,800	20,805	2,500	8,647	1,900	2,400
1965	4,800	2,538	2,500	3,035	1,900	830
Total	241,200	195,004	73,417	100,366	3,290	5,270

[1] Annual data derived by averaging.

Figure 4.--Dense second-growth ponderosa pine.

There were no serious forest fires in the watershed during 1920-65. Most involved a quarter of an acre or less, and the largest recorded fire, only 85 acres. A review of the fire records shows damage has generally been minor. Fire history of the watershed is summarized below.

Period	Total number of fires	Total acres burned
1920-29	119	330
1930-39	119	119
1940-49	152	200
1950-59	52	19
1960-65	84	18
Total	526	686

Hydrologic Relations

The principal method of relating available precipitation and streamflow data for Ochoco Creek was the double-mass curve. In application, the graph of the cumulative data of one sequential variable plotted against the cumulative data of a related sequential variable is a straight line if the relation between the variables is fixed. If the relation changes

Figure 5.--Typical logging spur road. Disturbed areas are seeded to grasses.

during the plotted sequence, due either to a change in data collecting techniques or to some physical change, a break or change in slope will appear. Statistical tests for significance of apparent slope breaks can be made *(16)*.

Precipitation-Runoff Relations

Precipitation stations within or closely adjacent to the Ochoco Creek basin, with periods of records long enough to be useful in analysis, are at Prineville, Oreg. (1897 to present) and Ochoco Ranger Station (1936 to present). Annual precipitation amounts recorded at these locations appear in table 4.

Ochoco Reservoir, essentially containing the outflow of Ochoco Creek, has been in continuous operation by the Ochoco Irrigation District since 1920. Records of reservoir level, flow in irrigation feed canals, and flow of Ochoco Creek below the reservoir are convertible to reservoir inflow. Annual inflows for water years[2] 1922-65 are shown in table 4.

The first step in analysis of Ochoco Creek hydrologic data was to check the consistency of precipitation records at Prineville and Ochoco Ranger Stations. A double-mass plot (fig. 6) of the annual precipitation report of these two stations shows a distinct slope break at the water year 1957. The double-mass plotting of each of these stations individually against a third station, nearby but outside the Ochoco drainage, determined that the slope break was attributable to a change at the Prineville station. Subsequent inquiry disclosed that about 1956 the Prineville station was moved nearly 3 miles to a new Weather Bureau cooperator location. The curve in figure 6 was used to adjust Prineville precipitation data subsequent to 1956 to make it consistent with prior records.

Precipitation at both stations and Ochoco Reservoir inflow were then related by use of

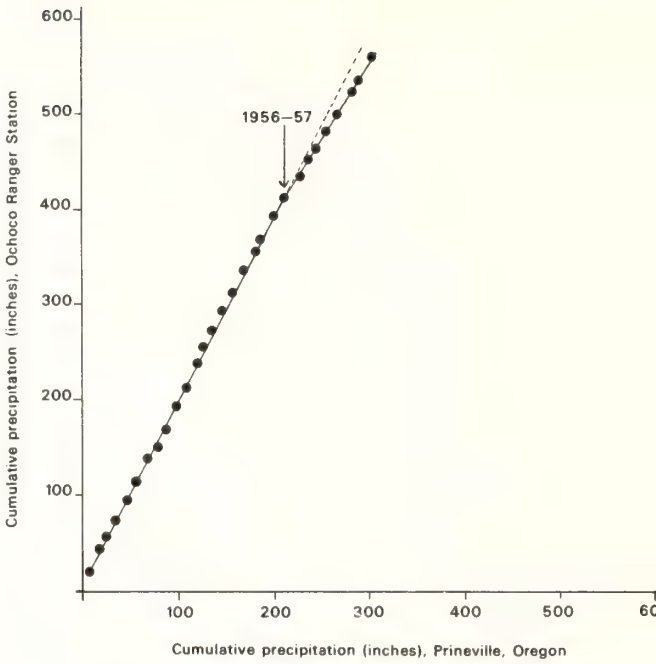

Figure 6.--Double-mass curve of precipitation data.

double-mass plots (figs. 7 and 8). Because the relation between precipitation and streamflow is seldom a constant ratio, these curves are not intended for analysis. Rather, they are useful only if we look at trends or possible changes in precipitation-runoff relations for further analysis.

Figure 7, the double-mass plot of Prineville precipitation and Ochoco Reservoir inflow, shows two distinct slope breaks which suggest changes in precipitation-streamflow relations. The first is a sharp break at water year 1942. The second and less distinct break occurred at water year 1956.

Figure 8, relating precipitation at Ochoco Ranger Station to reservoir inflow, also shows a distinct break at water year 1942 and a less distinct break at water year 1957.

[2]In this report, a water year begins October 1 and ends September 30. Numerical designation is the calendar year in which the water year ends.

Table 4.--*Annual precipitation amounts, Prineville and Ochoco Ranger Station, and Ochoco Reservoir inflow, 1922-65*

(Inches)

Water year	Precipitation		Inflow, Ochoco Reservoir
	Prineville	Ochoco Ranger Station	
1922	8.63	--	2.84
1923	11.85	--	2.57
1924	7.98	--	0.89
1925	11.48	--	2.89
1926	7.59	--	.87
1927	8.38	--	3.24
1928	6.98	--	2.83
1929	4.49	--	.46
1930	8.60	--	.28
1931	6.84	--	.40
1932	7.75	--	2.37
1933	7.07	--	1.45
1934	9.11	--	.17
1935	8.26	--	1.15
1936	11.13	--	1.61
1937	8.98	20.50	1.72
1938	10.31	22.96	3.55
1939	4.98	14.29	.83
1940	10.76	15.17	1.59
1941	11.16	21.02	1.21
1942	11.23	18.53	3.24
1943	12.31	25.39	6.29
1944	10.31	12.32	.70
1945	9.19	18.94	2.62
1946	9.90	23.15	6.77
1947	9.34	19.75	1.42
1948	12.55	[1]26.16	5.88
1949	5.91	[1]15.40	4.15
1950	8.15	17.66	[1]4.26
1951	11.08	[1]20.70	5.93
1952	12.00	20.12	4.57
1953	11.89	23.91	4.12
1954	11.20	19.21	3.22
1955	5.08	14.11	1.09
1956	14.16	24.14	6.08
1957	11.37	17.39	[1]3.24
1958	16.28	25.40	5.46
1959	8.11	14.63	1.15
1960	7.72	13.33	1.44
1961	11.82	17.52	2.37
1962	11.84	18.21	3.39
1963	13.73	20.72	3.18
1964	7.69	14.73	1.46
1965	14.68	24.34	5.77

[1]Estimated in part.

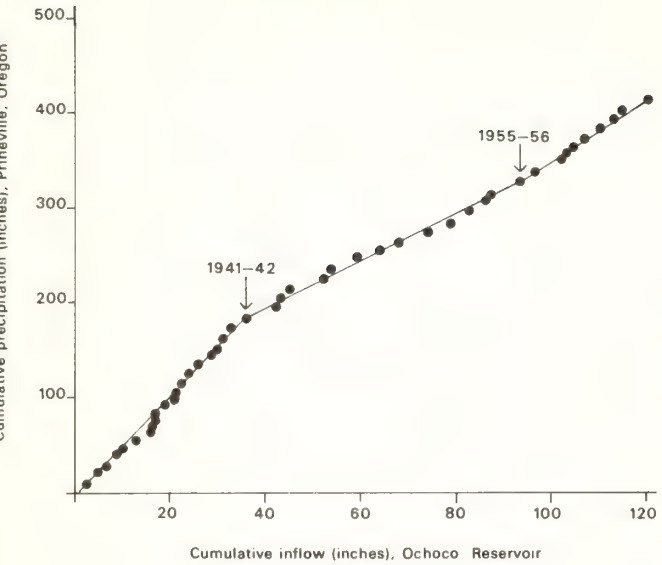

Figure 7.--Double-mass curve of precipitation and reservoir inflow.

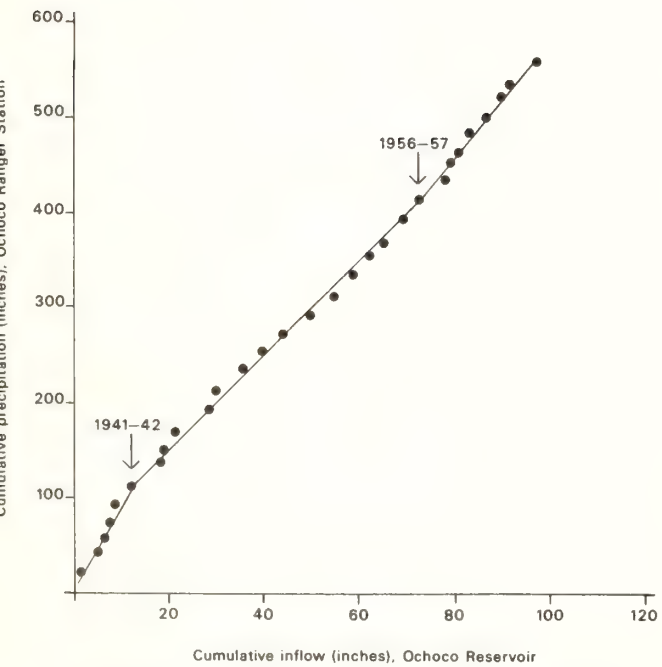

Figure 8.--Double-mass curve of precipitation and reservoir inflow.

Double-Mass Analysis

An analysis relating precipitation at Ochoco Ranger Station to Ochoco Reservoir inflow would be desirable, because that station is located near the center of the basin. However, since precipitation records prior to 1937 are not available, it became necessary to use the longer Prineville precipitation records in the analysis.

When the double-mass curve is used in an analysis of precipitation–runoff relations or streamflow trends, the cumulative measured flow should be plotted against a cumulative computed or pattern flow based on some determined precipitation-runoff relation. A variable ratio between precipitation and streamflow violates the theory of double-mass analysis.

A means for computing pattern inflow at Ochoco Reservoir was developed by relating cumulative annual precipitation at Prineville to cumulative annual reservoir inflow for water years 1922 to 1942 (see fig. 7) through a least squares fit linear regression.[3] This regression equation was then used in computing cumulative pattern inflow for each water year from 1922 to 1965.

Figure 9 is the resulting double-mass plot of computed pattern inflow against measured inflow into Ochoco Reservoir.

A number of year-to-year breaks are evident in figure 9. However, most users of double-mass curves recognize that short-term changes can be due to chance and generally choose to ignore breaks persisting for less than 5 years. Two distinct slope breaks persisting for more than 5 years are identifiable at water years 1942 and 1958. The first, indicating increased flow during water years 1942 to 1958, represents a departure from pattern flow of +2.21 inches per year. During the period 1958 to 1965, the departure from pattern flow amounted to +1.03 inches per year.

[3] $\hat{y} = 2.27 + 0.1826X$; $r = 0.994$
where X = cumulative precipitation, in inches, at Prineville, Oreg.
$\hat{y}$ = estimated cumulative inflow in inches.

To determine whether the apparent slope breaks in figure 9 occurred by chance, statistical tests of significance were made by methods of covariance. The periods 1942-58 and 1958-65 were tested against the period 1921-42. Differences were found to be highly significant[4] in both cases. The difference between the 1942-58 and the 1958-65 periods was found to be significant at the 95-percent confidence level.

These statistical tests show that increased streamflow subsequent to 1942 did not occur due to chance. They show further that the 1.18 inches average decrease in annual flow after 1958 is a real change.

The recognized slope breaks indicate times at which inconsistencies or changes occurred in the relation between pattern and measured flows. The difference in slopes of the lines on either side of the breaks indicates the extent of the change. With reasonable assurance that data collection methods have not changed, the need remains to identify plausible events or physical changes which coincide with slope breaks. Knowing the approximate timing of changes in streamflow relationships, one may analyze the history of Ochoco Creek for causes. However, such analysis is necessarily qualitative due to the general character of certain use data.

The possibility exists that streamflow relations changed in response to a persistent climatic change. Though annual precipitation amounts at Prineville during the period 1922-65 are essentially a normal distribution, mean annual precipitation during 1943-58 was nearly 2 inches greater than during 1922-42. However, from prediction equations developed for both periods,[5] a streamflow increase of only 0.5 to 0.7 inch would be the expected result of a 2-inch increase in annual precipitation.

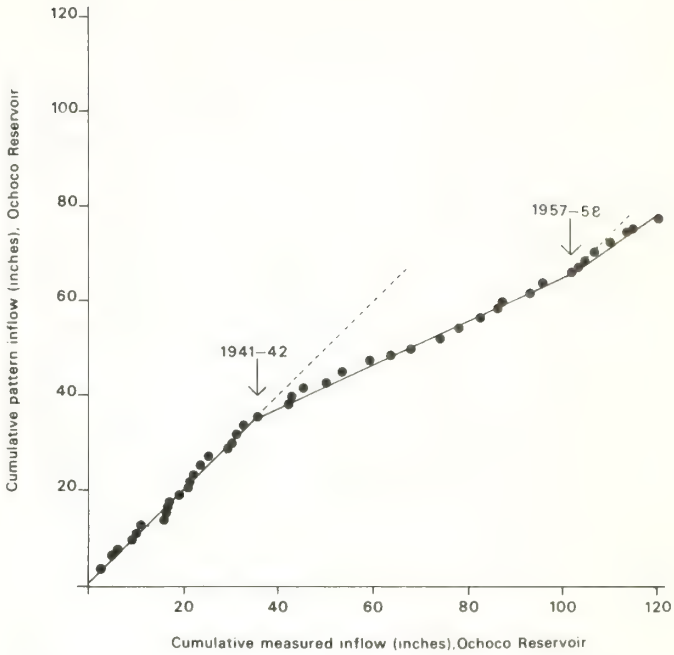

Figure 9.--Double-mass curve of measured and pattern inflow.

Certain land use activities, such as diversions for irrigation agriculture above the reservoir and for forest grazing, have been essentially stable throughout the period studied. Consequently, they provide no logical explanation for streamflow changes. Other uses, such as recreation and mining, either alter the landscape very little or occupy such minute portions of the basin that they also fail to suggest causes for major changes in hydrologic response. Similarly, fires have been but minor events in land use history.

Timber harvest is the only recorded major land use on Ochoco Creek which might conceivably result in a significant change in water yield. And intensification of timber harvest activity, beginning in 1938 and peaking in 1949, is approximately coincident with the first break identified in the double-mass curve (fig. 9).

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[4] Significant at the 99-percent confidence level.

[5] $\hat{y} = 0.24X - 0.38$; $r = 0.48$
$\hat{y} = 0.36X + 0.27$; $r = 0.52$
where X = annual precipitation, in inches, at Prineville, Oreg.
$\hat{y}$ = estimated annual inflow, in inches, at Ochoco Reservoir.

The slope break occurring about water year 1958, manifested as a streamflow decrease of 1.18 inches per year, does not coincide with any particular recorded activity. It may represent a trend toward original flow values, similar to trends observed in water yield experiments dealing with forest cutting. Commercial timber harvest during 1938-49 removed high per-acre volumes from mature stands. Dense second-growth stands resulting from this heavy cutting now fully occupy most of these sites. Since 1951, timber harvesting generally has been on a sanitation salvage basis removing low per-acre volumes. These two factors — full stocking of older cutover by dense second growth, and general reduction of timber harvest — could conceivably combine in higher transpiration draft, thus decreasing water yield.

Sedimentation

There are no formal records of sedimentation in Ochoco Reservoir. The manager of the Ochoco Irrigation District, a longtime resident of the area, believes that in the past 45 years the reservoir capacity has been reduced 250 to 500 acre-feet by sediment. He further believes that most of this sediment is the result of two major December-January floods in 1945-46 and 1964-65. No reservoir management or irrigation problems have resulted from either suspended or deposited sediments.[6]

SUMMARY

The prosperity of the West greatly depends on adequacy of water supplies. Though much water use is at considerable distance from the forest, forest lands are intimately related to western irrigation in that they are the origin of perhaps 85 percent of the water. In central Oregon, water will probably fix the upper limits of population and living standards.

In this case study, the hydrologic performance of a 295-square mile drainage in central Oregon was compared with the land use history for the period 1921-65. Two distinct changes in streamflow regimen were identified. The first, beginning about water year 1942, was an increase of 2.21 inches in average annual yield. The timing of this increase is approximately coincident with the onset of timber harvesting activity in the basin. The second change was a decrease of 1.18 inches in average water yield beginning about 1958. This change could possibly be related to the full stocking of cutover lands by dense, second-growth stands and a general reduction of timber harvest activity.

Though more sensitive, refined tests of the influence of timber harvest on water yield are needed for stands east of the Cascade Range, the analyses in this report show that accepted management practices for vegetative types found on Ochoco Creek have favored water yields.

[6]Personal communication, Mr. LaSelle E. Coles, Ochoco Irrigation District Manager, Prineville, Oreg., June 23, 1969.

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Impregnating and Coating with Endrin to Protect Douglas-fir Seed from Rodents

AFR 6 1970

Use Pesticides Safely
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INTRODUCTION

Reforestation with coniferous seed is often prevented by various biota which destroy disseminated seed before germination. Although the relative importance of destructive agents varies by area, seed species, and year, seed-eating rodents are generally held responsible for the greatest seed losses in the Pacific Northwest. Various measures have been used to reduce rodent impacts and enhance reproduction from sown seed. At present, the most common protective treatment of seed is with endrin.[1/]

The U.S. Bureau of Sport Fisheries and Wildlife recommends endrin as a seed coating at 0.5 percent, with an adhesive to hold it to the seedcoat and a coloring material for identification. Although early field tests showed that adequate stocking with Douglas-fir *(Pseudotsuga menziesii* (Mirb.) Franco) was possible when endrin-coated seed was used (Dimock 1957, Hooven 1957, Dick et al. 1958),[2/] failures have occurred in many operational seedings. Many forest managers, therefore, have recently questioned the effectiveness of the recommended 0.5-percent treatment and have often employed much higher concentrations of endrin.

Endrin was introduced in 1956 as an interim seed protectant until a better compound became available. Since that time, emphasis has been on a search for new biologically active chemicals to replace endrin. Unfortunately, this effort has not been successful. Today, endrin remains the only chemical recommended for protecting seed from rodents; yet, only empirical guidelines for its use are available. Since the midfifties, endrin has been used in varying concentrations, with different coating methods, and in combinations with other chemical ingredients. Despite such trials, no substantial improvements in the basic treatment have either been verified or become generally accepted. Further, there is still no agreement on the effectiveness of endrin in protecting Douglas-fir seed or its effect on seed viability.

In the experiments reported here, therefore, we have attempted to evaluate endrin critically, using four seed lots, two methods of germination, and two bioassay techniques. The chemical was applied to seed by a conventional coating method at two levels, using the most common adhesive and coloring material, and by impregnation. We treated small and large batches of seed, simulated seeding by helicopter, and determined endrin content of seed from the different treatments.

[1/] 1, 2, 3, 4, 10, 10-hexachloro-6, 7-epoxy-1, 4, 4a, 5, 6, 7, 8, 8a-octahydro-1, 4, 5, 8-endo-endo-dimethanonaphthalene.

[2/] Names and dates in parentheses refer to Literature Cited, p. 17.

EXPERIMENTAL

Seed.-- Four lots of western Washington Douglas-fir seed were obtained from the Washington State Department of Natural Resources and used for testing. Available information for each lot is shown in table 1.

Table 1.--*Seed data as determined by the Washington State Department of Natural Resources just prior to storage*

Seed lot number	Year collected	Elevation	Purity	Moisture content	Number of seeds per pound
		- - Feet - -	*- - - Percent - - -*		
1	1964	1,100-1,500	97.5	5.6	44,039
2	1964	1,200-1,700	96.0	8.4	44,470
3	1965	1,200-1,600	95.3	7.5	40,504
4	1966	2,000	97.5	8.0	40,500

We used lots 1-3 in experiment 1, lot 1 in experiments 2-5, and lot 4 in experiment 6. All seeds were kept in moisture-proof containers at about -4° C. until needed.

Test animal.-- Deer mice *(Peromyscus maniculatus)*, live-trapped in a deforested site adjacent to standing second-growth Douglas-fir timber about 1 mile southeast of Tumwater, Wash., were used in all bioassay tests. All mice were trapped from October through April when Douglas-fir seed is usually available. The animals were brought to the laboratory, placed in individual cages, and supplied with water and commercial pelleted ration until tests were conducted.

Seed treatments.-- Seeds were treated as follows:

1. *Control:* Seed was not chemically treated.
2. *Endrin-coated:* Endrin 50-WP (50-percent wettable powder) from Stauffer Chemical Company[3/] was used. Seed was wet

[3/] Mention of chemical companies and their products does not represent endorsement by the Forest Service or by the Department of Agriculture.

with a slurry of endrin in Dow Latex 512-R adhesive, covered with aluminum powder, spread in a thin layer, and allowed to dry overnight under a fume hood. The two coating treatments used in the tests were:

a. *0.5-percent endrin* (0.5 EC): Endrin was added at the 0.5-percent level as recommended by the U.S. Bureau of Sport Fisheries and Wildlife.

b. *1.0-percent endrin* (1.0 EC): Endrin concentration was double the recommended rate. Seed treated at this higher concentration is now used by many foresters in operational direct-seedings.

Endrin-coated seed was prepared in 1/2-pound batches in glass jars, except in experiment 6 where 10 pounds of seed were coated in a cement mixer in a typical commercial manner.

3. *Endrin-impregnated:* Seed was dried in a forced-air oven at 40° C. for 24 to 48 hours to reduce moisture content to about 6 percent prior to impregnation. Preliminary experiments showed that this pretreatment does not affect viability of Douglas-fir. Also, as with seed treated with other chemicals (Jones and Havel 1968), our unpublished data showed that a low moisture content was necessary to minimize injury to seed during impregnation.

Effects of several endrin solvents on viability of Douglas-fir seed were studied in preliminary experiments. For the impregnation studies reported here, we selected the two solvents which appeared most promising.

Solutions containing 2 percent endrin were prepared by dissolving appropriate amounts of Endrin 50-WP in each of the two selected solvents and filtering out the inactive, insoluble ingredients of the wettable powder. Dried seeds were then soaked in the endrin solutions for predetermined time periods and were finally dried in a forced-air oven at 40° C. for 24 hours to remove the solvent from the seed without affecting the endrin.

The two endrin-impregnation treatments used in the tests were:

a. *Endrin-dichloroethane* (EDI): Endrin was dissolved in 1,2-dichloroethane (D).

b. *Endrin-trichloroethylene* (ETI): Endrin was dissolved in trichloroethylene (T).

In experiment 6, 10 pounds of seed were treated in a special impregnation container designed to handle up to 14 pounds of seed. In all other experiments where impregnated seed was used, the needed small amounts of seed were treated by enclosing seeds in cheesecloth and dipping them in solutions contained in beakers.

4. *Solvent-impregnated:* To separate effects of endrin from those of the solvent, dried seed was soaked in each of the two selected solvents in the same manner and for the same periods of time as were the small batches of endrin-impregnated seed. This seed was also dried at 40° C. for 24 hours after treatment. The solvent-impregnated treatments were:

   a. *Dichloroethane* (DI): Seed was soaked in the (D) solvent.

   b. *Trichloroethylene* (TI): Seed was soaked in the (T) solvent.

Additional information about the treatments is given with each experiment as required.

Germination.--Four 100-seed replicates were germinated on perlite at 24° ± 1° C. after stratification for 21 days at 3° to 5° C., as prescribed in the standard test (Association of Official Seed Analysts 1965). Germinants were counted at weekly intervals for 4 weeks.

Production of seedlings and seedling growth were also studied concurrently with the perlite germination tests. Two additional 100-seed replicates of stratified seed were planted about 1/8-inch deep in 4- by 4-inch pots containing equal amounts of soil, vermiculite, and peat moss. For germination and initial growth, pots were placed in a plant growth chamber and watered daily. The chamber was set for 27° C. and 800 foot-candles (ft.-c.) of light for 20 hours per day and 21° C. for 4 hours of darkness; relative humidity was about 70 percent. At the end of 28 days, the pots were transferred to another chamber and watered every 2 days. Temperatures were 27° C. during the day and 17° C. at night. Other growth conditions were 60- to 80-percent relative humidity and 1,200 ft.-c. of fluorescent-incandescent light on a 14-hour photoperiod. Seedlings were harvested and counted 50 days after planting. Roots were washed, severed at the root collar, and discarded after examination. The tops of 10 seedlings, selected at random from each pot, were cut into small segments and dried to constant weight in a forced-air oven at 65° C.

Bioassay.-- Bioassays were conducted whenever the number of mice caught was sufficient for a minimum of one test. Tests, therefore, were conducted at different times, but each test was run with freshly caught mice. One day prior to each test, mice, in individual cages supplied with pelleted food and water, were offered a number of Douglas-fir seed equal to that subsequently used in the test; animals not consuming at least 90 percent of the untreated seeds were rejected. Treatments were assigned at random to remaining mice. Water and food were available *ad libitum*.

Number of mice per treatment, number of seed offered each test day, and duration of tests varied in the four experiments involving mice. Thus, we used 12 mice and 80 seeds per day per mouse for 2 consecutive days in experiment 2 and the same conditions with washed seed in experiment 4; a 10-animal, 40-shelled seeds, 2-day test in experiment 4; and a 10-animal, 10-seed, 5-day test in experiments 5 and 6. Seed consumption was recorded daily, and the numbers of dead mice were noted each day during the test and for 2 days following.

Endrin content.-- Endrin was extracted from seed by a double extraction technique to ensure maximum recoveries. Duplicate samples of 200 seeds each were pulverized in a Virtis homogenizer with 50-ml. portions of Skellysolve B:isopropyl alcohol (4:1 by volume). Extracts were separated from the slurry by filtration, and residual seed material was reextracted with Skellysolve B for 20 hours in Soxhlet apparatus. Extracts were combined and evaporated to dryness in a rotary vacuum evaporator. Extracted fats were saponified by adding 25-ml. portions of 95-percent ethyl alcohol:50-percent potassium hydroxide (4:1 by volume) to the residues and refluxing for 2 hours on a hot plate. The saponified solutions were cooled, diluted with equal volumes of water, and extracted with four 20-ml. portions of Skellysolve B. Skellysolve B extracts containing the endrin were combined and washed with water until neutral to phenolphthalein. Extracts were then dried over anhydrous sodium sulfate, made up to volume with hexane, and analyzed for endrin.

Amounts of endrin in the extracts were determined by gas chromatography using an Aerograph Model 1840-1 instrument equipped with an electron capture detector and a 5-foot by 1/8-inch I. D. glass column packed with 6-percent SE-30 on 80- to 100-mesh Varaport-30. Injector, column, and detector temperatures were 200°, 190°, and 200° C., respectively. Nitrogen was used as carrier gas at a flow rate of 40 ml. per minute. Endrin was quantified by peak height, and data were appropriately corrected according to recovery analyses of known quantities of endrin added to blank seed samples.

Experiment 1

Using three seed lots, we studied effects of two endrin coatings, two impregnations with endrin solvents, and two endrin impregnations on seed germination and ability to produce normal seedlings. With the solvent- and endrin-impregnations, we also determined effects of five different soaking times. Because of limited germination facilities, we were unable to evaluate all treatments simultaneously and the experiment, therefore, consisted of five separate tests. Each test included a control, the two endrin coating treatments, and one soaking time period for each of the four solvent- and endrin-impregnation treatments. Soaking periods were 1/2, 1, 1-1/2, 2, and 2-1/2 hours in tests 1, 2, 3, 4, and 5, respectively. In addition, coated and impregnated seeds were freshly prepared for each test, and control seed was always drawn from cold storage immediately before testing.

Results.-- Germination of untreated seed was almost always better on perlite than in soil (table 2). In both media, seed performance differed among lots, with germination highest in lot 1, intermediate in lot 2, and lowest in lot 3. Also, average dry weights of individual seedling tops from untreated seed varied slightly by lot, but trends were not consistent between tests.

Gross comparisons of average dry weights of seedling tops and appearance of the roots indicate that seedling growth was not affected by treatment. Germination data, however, show that treatment affected the seed. Effects varied among treatments and, in most, germination percents in soil were

Table 2.-- *Germination of treated and untreated Douglas-fir seed on perlite and in soil, and ovendry weight of seedling tops produced in soil*

Seed treatment[1]	Seed lot 1			Seed treatment[1]	Seed lot 2			Seed treatment[1]	Seed lot 3		
	Perlite	Soil	Dry weight[2]		Perlite	Soil	Dry weight[2]		Perlite	Soil	Dry weight[2]
	Percent[3]		mg.		Percent[3]		mg.		Percent[3]		mg.
					TEST 1						
Control	90	81	31	Control	86	78	26	Control	78	69	25
DI	88	80	30	EDI	84	78	27	EDI	75	78	31
EDI	86	84	30	DI	82	82	29	1.0 EC	74	64	27
0.5 EC	82	80	33	TI	81	70	28	0.5 EC	74	70	33
1.0 EC	82	82	26	ETI	80	72	24	DI	73	74	32
TI	80	84	32	1.0 EC	79	80	33	TI	72	70	25
ETI	78	76	31	0.5 EC	74	79	31	ETI	68	65	32
					TEST 2						
Control	98	79	29	Control	83	78	24	0.5 EC	82	74	26
DI	96	88	25	DI	81	86	28	Control	78	76	22
0.5 EC	90	83	32	EDI	80	78	34	DI	74	76	30
EDI	82	84	29	1.0 EC	79	82	28	EDI	72	74	33
TI	82	84	26	TI	78	80	30	TI	72	70	33
1.0 EC	81	86	25	0.5 EC	77	79	27	ETI	65	74	26
ETI	76	84	30	ETI	75	76	25	1.0 EC	65	76	33
					TEST 3						
Control	90	85	32	Control	88	87	33	0.5 EC	80	78	29
0.5 EC	88	72	31	0.5 EC	84	80	28	Control	80	76	29
DI	86	89	33	1.0 EC	83	76	26	1.0 EC	79	75	28
1.0 EC	82	81	29	DI	82	87	31	DI	74	84	33
EDI	81	90	32	EDI	80	84	33	EDI	72	85	27
TI	72	76	30	TI	70	76	35	TI	62	66	33
ETI	70	75	33	ETI	66	72	31	ETI	58	66	31
					TEST 4						
Control	94	83	27	Control	83	85	27	Control	81	77	26
1.0 EC	88	85	29	0.5 EC	82	86	25	DI	79	84	23
0.5 EC	86	82	28	EDI	80	84	24	0.5 EC	78	78	26
DI	84	87	24	DI	80	82	29	1.0 EC	75	74	29
EDI	83	92	24	1.0 EC	78	84	30	EDI	75	77	26
TI	60	76	24	ETI	61	78	27	ETI	57	64	29
ETI	58	78	31	TI	54	72	23	TI	53	64	28
					TEST 5						
0.5 EC	88	83	25	0.5 EC	84	74	27	Control	80	76	25
Control	88	86	22	Control	82	82	20	1.0 EC	80	79	27
DI	86	88	26	1.0 EC	82	81	24	0.5 EC	78	75	27
EDI	86	84	25	DI	81	90	21	DI	73	77	22
1.0 EC	84	82	25	EDI	80	82	27	EDI	70	80	23
TI	54	74	24	TI	51	67	22	TI	40	67	26
ETI	52	74	22	ETI	44	71	24	ETI	38	66	26

[1] Control = untreated, 0.5 EC = endrin-coated at 0.5 percent, 1.0 EC = endrin-coated at 1.0 percent, DI = dichloroethane-impregnated, TI = trichloroethylene-impregnated, EDI = endrin-dichloroethane-impregnated, and ETI = endrin-trichloroethylene-impregnated.

For solvent- and endrin-solvent-impregnation treatments, seed was soaked for ½, 1, 1½, 2, and 2½ hours in tests 1, 2, 3, 4, and 5, respectively. Impregnated and coated seeds were freshly prepared for each test.

[2] Ovendry weights of tops per seedling are averages of 20 seedlings, 10 tops from each of two pots.

[3] Germination percents are averages of four and two replications each for perlite and soil tests, respectively. Within each test, means in the perlite column enclosed by the same line(s) do not differ significantly at the 5-percent level, using Tukey's test (Snedecor 1961).

higher than on perlite. This trend is opposite that of untreated seed but agrees with performance of many seed lots recently reported by Stein (1967).

Endrin coatings significantly reduced germination on perlite in two comparisons. Also, two germinations in soil from coated seed were less than the controls by more than 10 percent.

Performance of EDI seed was similar to that of coated seed on perlite and in soil and compared well with germination of the controls in soil. However, EDI seed germination on perlite was significantly lower than that of DI and control seed in about 20 percent of the comparisons. Also, its germination in soil in two comparisons was 8 percent lower than that of the DI seed.

Performance of ETI seed was not as good as that of the EDI seed especially when seed was soaked for more than 1 hour. Its germination on perlite was significantly lower than that of TI seed in about 20 percent of the comparisons and was mostly inferior to that of seed from the other treatments. With few exceptions, germination of ETI seed in soil was higher than on perlite. Thus, performance of this seed in soil was comparable with that of TI seed and was only somewhat lower than that of seed from the other treatments in most comparisons.

Experiment 2

Using seed from lot 1, this bioassay was conducted to compare effects of two coating and four impregnation treatments on seed consumption by deer mice. The coating treatments, 0.5 EC and 1.0 EC, are typical of those currently employed in the Pacific Northwest. The impregnation treatments involve use of two endrin solvents and soaking times of 1 hour (EDIa and ETIa) and 2-1/2 hours (EDIb and ETIb), as these appeared to provide measurable treatment effect.

Seed was bioassayed in a 12-animal, 80-seeds per animal per day, 2-day test. The 80-seed offering was selected after preliminary feeding trials showed that virtually all mice would readily eat 80 untreated seeds per day and many would eat 80 or more treated seeds of at least one of the treatments.

Results.-- All treatments reduced feeding (table 3). Although significantly better than the control, the 0.5 EC was only about half as effective as any of the other treatments. Increasing the concentration from 0.5 to 1.0 EC greatly improved effectiveness of the treatment.

The tests revealed no differences in feeding by mice on impregnated seeds which were all as effective as the 1.0 EC. Endrin impregnation with either the D or T solvent gave similar reductions in feeding, but individual consumption was somewhat more variable among mice fed the ETI treatments. Increasing the soaking time from 1 to 2-1/2 hours gave no apparent benefit.

Mortality resulted from all endrin treatments, and highest mortality occurred with impregnation and 1.0 EC treatments. Again, doubling the concentration from 0.5 to 1.0 EC nearly doubled mortality. Mortality was similar within the 1-hour impregnation treatments but was somewhat less when the soaking time was increased to 2-1/2 hours.

Table 3.--*Consumption of endrin-treated Douglas-fir seed by deer mice and resulting animal mortality*

Treatment[1/]	Seed consumption[2/]		Animal mortality
	- Mean number -	*- - - Percent - - - -*	
Control	160a	100	0
0.5 EC	96b	60	42
ETIa	48c	30	92
1.0 EC	48c	30	92
ETIb	45c	28	75
EDIb	41c	26	67
EDIa	40c	25	92

[1/] Control = untreated, 0.5 EC = endrin-coated at 0.5 percent, 1.0 EC = endrin-coated at 1.0 percent, EDIa = endrin-dichloroethane-impregnated for 1 hour, EDIb = endrin-dichloroethane-impregnated for 2½ hours, ETIa = endrin-trichloroethylene-impregnated for 1 hour, ETIb = endrin-trichloroethylene-impregnated for 2½ hours.

[2/] 12-animal, 80-seeds per animal per day, 2-day test.

[3/] Means followed by the same letter do not differ significantly at the 5-percent level, using Tukey's test (Snedecor 1961).

Experiment 3

The biological activity of endrin-treated seed against mice depends on its endrin content and the distribution of the chemical on and in the seedcoat and within the seed. In this experiment, therefore, we determined endrin content of: (1) seed coated with endrin at the recommended 0.5-percent level, (2) 1.0-percent endrin-coated seed similar to that used by many foresters, and (3) endrin-impregnated seed, EDIa, which showed satisfactory germination in experiment 1 and biological activity equal to that of the 1.0 EC seed in experiment 2. Further, we washed EDIa seed repeatedly with water to remove surface endrin, shelled the washed seed (EDIa-w), and determined the endrin content of resulting seedcoats and "endosperms."[4/] Seed from lot 1 was used throughout the experiment.

Results.--Because endrin losses are inherent in the seed-coating method, 0.5 EC and 1.0 EC seed contained only 62 and 83 percent, respectively,

[4/] "Endosperm" denotes all material inside the seedcoat.

Table 4.--*Endrin content of coated and impregnated Douglas-fir seed*

Treatment[1/]	Seed part analyzed	Endrin content	
		μg.[2/]	*Percent*
0.5 EC	Whole seed	32.0	0.31
1.0 EC	Whole seed	85.5	.83
EDIa	Whole seed	40.0	.39
EDIa-w	Seedcoat	22.0	--
EDIa-w	"Endosperm"	4.1	--

[1/] 0.5 EC = endrin-coated at 0.5 percent, 1.0 EC = endrin-coated at 1.0 percent, EDIa = endrin-dichloroethane-impregnated for 1 hour, EDIa-w = same as EDIa but treated seed was washed 10 times with water.

[2/] Determined by gas chromatography; each value is the average of two determinations.

of the actual amounts of endrin applied to them. Endrin content of whole EDIa seed was less than half that in the 1.0 EC seed, 25 percent more than in seed from the 0.5 EC treatment, and 22 percent less than the recommended 0.5-percent level (table 4). Unlike coated seed where endrin was limited to seed surfaces, impregnated seed contained endrin on the surface, in the seedcoat, and in the "endosperm." Also, total endrin content of EDIa seed after washing indicates that most of the endrin was closely tied to the impregnated seed.

Experiment 4

After being sown in the field, endrin-impregnated seed would likely lose some endrin by weathering. To evaluate the effect of such losses, we bioassayed washed endrin-impregnated seed (EDIa-w) similar to that used in experiment 3. We also shelled washed seed and bioassayed the "endosperms" to determine the protective value of endrin inside the seed. We used 10-animal, 2-day tests with 80 washed seeds and 40 "endosperms" per animal per day. Fewer "endosperms" were offered because of the difficulty in removing seedcoats to obtain the test material.

Results.--Consumption of EDIa-w seed and "endosperms" was considerably less than untreated seed (table 5). Percents of washed seed eaten were similar to those of the 1.0 EC and all the endrin-impregnated seed consumed in experiment 2. On the other hand, percent of "endosperms" eaten was higher, but the actual number taken was nearly the same as for the 1.0 EC and impregnated seed in experiment 2.

Table 5.--*Consumption of whole seed and "endosperm" of washed endrin-impregnated seed by deer mice and resulting animal mortality*

Treatment[1/]	Seed part bioassayed	Seed consumption[2/]		Animal mortality
		Mean number	- - - *Percent* - - - -	
Control	Whole seed	160± 1	100	0
EDIa-w	Whole seed	43±11	27	80
EDIa-w	"Endosperm"	39± 2	49	60

[1/] Control = untreated, EDIa-w = endrin-dichloroethane-impregnated seed (1 hour) washed 10 times with water to remove surface endrin.

[2/] 10-animal, 80-seeds per animal per day, 2-day test for whole seed and 10-animal, 40-"endosperms" per animal per day, 2-day test for "endosperm." Mean numbers are followed by confidence intervals (P = 0.05).

Consumption of both washed seed and "endosperms" resulted in death of sizable proportions of test animals. This mortality and the reduced seed consumption indicate that impregnated seed would probably retain its effectiveness in the field despite weathering.

Experiment 5

The previous experiments showed that among the endrin impregnations tested, the EDIa treatment was most promising. To substantiate earlier results and to investigate the main treatments further, we bioassayed EDIa seed again together with seed from the two coating treatments in the fall of 1968. Lot 1 seed was used as in earlier tests, but a different testing procedure was followed. With the 80-seed test used in experiment 2, most of the treated seed consumed was taken the first day of the 2-day test period presumably because the animals had ample opportunity to rapidly ingest greater numbers of seed than needed for aversion or mortality. In this experiment, therefore, we used a 10-animal, 10-seeds per animal per day, 5-day test in order to measure treatment effects over a longer period of time.

Results.--As in experiment 2, consumption of 1.0 EC and EDIa seed was markedly lower than that of untreated seed (table 6). However, unlike the earlier test (table 3), the 0.5 EC treatment did not reduce feeding significantly. In addition, percents of seed consumption with all treatments were

Table 6.--*Consumption of endrin-treated Douglas-fir seed by deer mice and resulting animal mortality*

Treatment[1/]	Seed consumption[2/]		Animal mortality
	Mean number[3/]	- - - - *Percent* - - - -	
Control	50a	100	0
0.5 EC	44a	88	30
EDIa	23b	46	80
1.0 EC	20b	40	50

1/ Control = untreated, 0.5 EC = endrin-coated at 0.5 percent, 1.0 EC = endrin-coated at 1.0 percent, EDIa = endrin-dichloroethane-impregnated for 1 hour.

2/ 10-animal, 10-seeds per animal per day, 5-day test.

3/ Means followed by the same letter do not differ significantly at the 5-percent level, using Tukey's test (Snedecor 1961).

higher than before, and with most treatments some seed was taken on each day of the 5-day test (fig. 1).

Mortality of test animals resulted from all endrin treatments as in experiment 2. Mortality percents, however, were lower than before, particularly with the coating treatments.

Experiment 6

Operational seedings with endrin-treated seed require treatment of 10- to 25-pound batches of seed, which are then sown by helicopter. Endrin content and biological activity of the seed immediately after treatment may differ from seed treated in small batches as in the previous experiments. Also, the same parameters may be reduced as treated seed passes through the helicopter's seed dissemination equipment. To test these possibilities, we divided 20 pounds of seed from lot 4 into two equal parts. Ten pounds were coated with endrin at the 1.0-percent level in a cement mixer, and the remainder was impregnated by the EDIa treatment using the apparatus shown in figure 2. One-pound samples of each treatment were run through the seeding equipment of a grounded helicopter; equipment was set at approximately the same speed usually used in actual seedings in the field. Subsamples of coated and impregnated seed, before and after the helicopter treatment, were then analyzed for endrin by gas chromatography and fed to deer mice in a 10-animal, 10-seeds per animal per day, 5-day test.

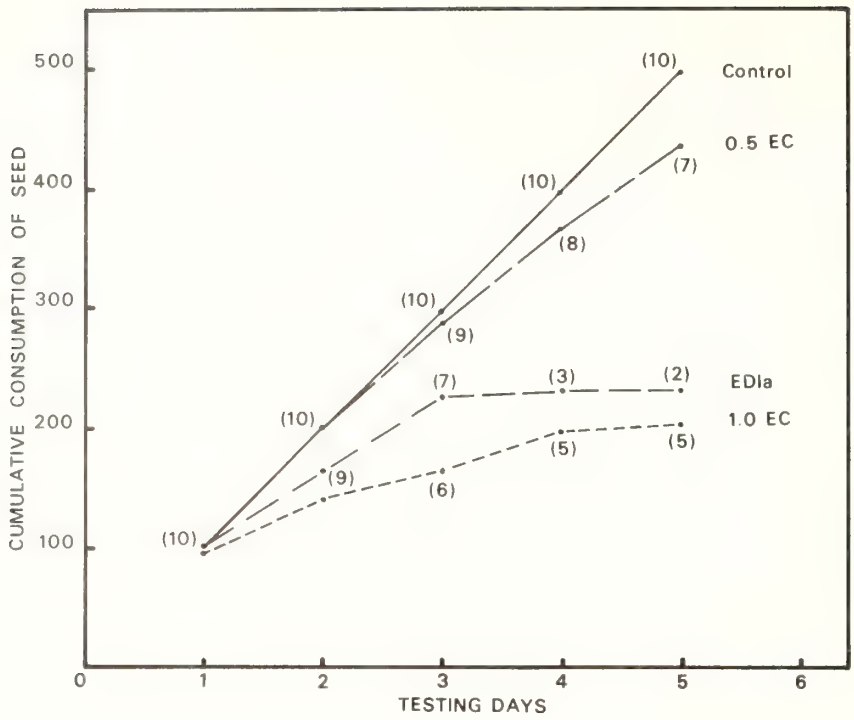

Figure 1.--Daily consumption of control and endrin-treated Douglas-fir seed by deer mice. (Numbers of surviving mice indicated in parentheses. Control = untreated, 0.5 EC = endrin-coated at 0.5 percent, 1.0 EC = endrin-coated at 1.0 percent, EDIa=endrin-dichloroethane-impregnated for 1 hour).

Results.-- Endrin contents of the 1.0 EC and EDIa seed (table 7) were similar to those obtained with seed treated in small batches in experiment 3 (table 4), although the endrin content of individual seed averaged slightly more than before probably due to differences in number of seed per pound between the lots used in the two experiments (table 1). Consumption by mice of coated and impregnated seed was, respectively, equal to and somewhat less than with the same two treatments in experiment 5 (table 6), and mortality of test animals in each treatment in the two experiments varied only slightly. Also, as in experiment 5, there was no significant difference in seed consumption between treatments, and mortality resulting from impregnated seed was higher than from the coating treatment.

Endrin content of coated and impregnated seed decreased slightly after helicopter dissemination, but the decrease was less for impregnated seed. Similarly, consumption of disseminated seed from each of the two treatments did not change significantly. However, mortality was somewhat higher among mice fed the coated seed and lower among those fed the impregnated seed after helicopter dispersal.

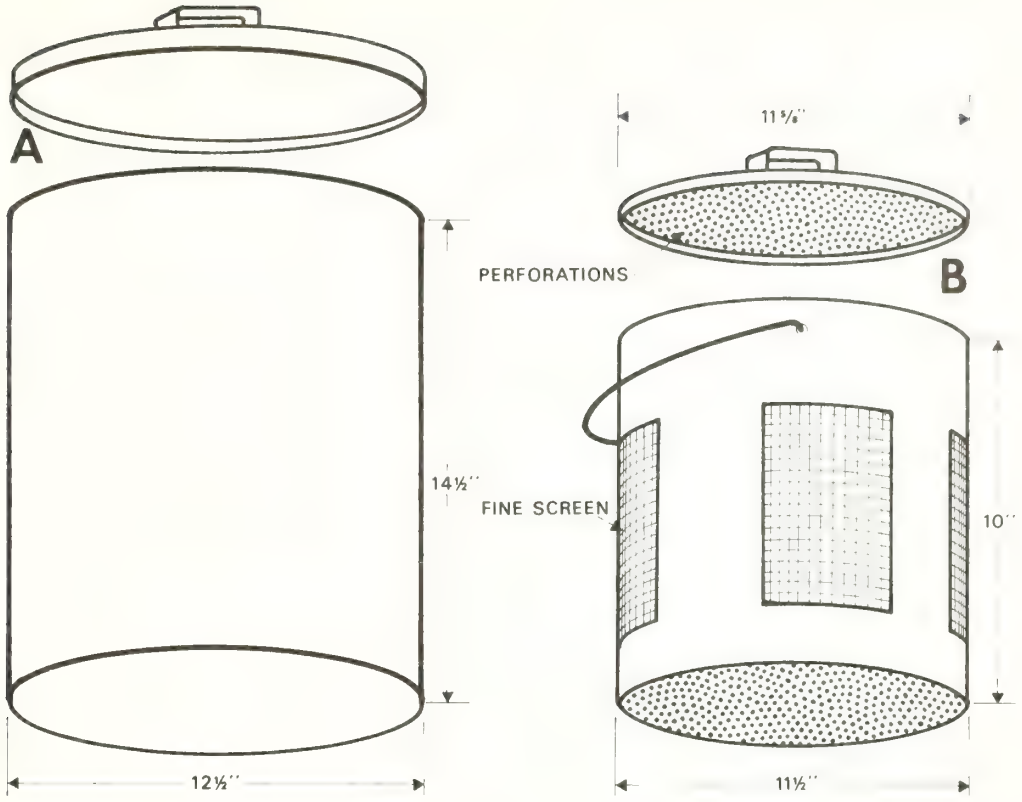

Figure 2.--Schematic diagram of apparatus used to impregnate seed in experiment 6. The apparatus, made of galvanized steel, consists of an outside container (A) to retain the endrin solution and an insert (B) to hold the seed

Table 7.--*Endrin content and consumption by deer mice of coated and impregnated Douglas-fir seed and resulting animal mortality before and after dispersal by helicopter*

Treatment[1/]	Endrin content				Seed consumption[2/]				Animal mortality	
	Before	After	Before	After	Before		After		Before	After
	μg. per seed[3/]		*Percent*		*Mean number*	*Percent*	*Mean number*	*Percent*	*Percent*	
1.0 EC	93.5	82.5	0.83	0.73	20a	40	19a	38	40	60
EDIa	51.0	47.0	.45	.42	15a	30	17a	34	90	70

[1/] 1.0 EC = endrin-coated at 1.0 percent in a commercial cement mixer; EDIa = endrin-dichloroethane-impregnated for 1 hour using apparatus shown in figure 2.

[2/] 10-animal, 10-seeds per animal per day, 5-day test. Means followed by the same letter do not differ significantly at the 5-percent level, using Tukey's test (Snedecor 1961).

[3/] Determined by gas chromatography; each value is the average of two determinations.

DISCUSSION

With few exceptions, endrin coating at both the 0.5- and 1.0-percent level produced satisfactory germinants on perlite and seedlings in soil. Several laboratory investigations showed germination inhibitions up to 20 percent after endrin treatment (Dimock 1957, Dick et al. 1958, Edgren 1968). However, we believe that slight inhibitions are unimportant in view of the inherent inaccuracy of all laboratory results when extrapolated to the field and because of the anticipated seed protection by the treatment. Likewise, we do not believe that the high inhibitions reported were due to endrin. Rather, we suggest that the inhibitions were caused by other factors, such as method of treatment, delay in testing germination after treatment without adequate drying of the seed, or chemical ingredient other than those used in our experiments.

Germination and seedling production from seed impregnated with endrin depended on the solvent used. Performance of seed treated with the (D) solvent alone or in combination with endrin was satisfactory and considerably better than that of the TI and ETI seed. It is evident, therefore, that 1,2-dichloroethane (Ethylene dichloride) is the preferred solvent for impregnating Douglas-fir seed with endrin and possibly with other chemical protectants. The solvent may also be useful in impregnating other conifer seed since our unpublished data[5/] indicate that seed of ponderosa pine *(Pinus ponderosa* Laws.) and longleaf pine *(Pinus palustris* Mill.) are not adversely affected by the treatment. Additional advantages of the solvent are: commercial availability at reasonable cost, relative nontoxicity to mammals, low flammability, and nonpersistency since it is easily evaporated at moderately low temperatures.

Endrin content of coated seed varied among the treatments. When seed was treated in small batches, the 0.5- and 1.0-percent coated seed contained 0.31 and 0.83 percent endrin, respectively. Similarly, seed from the 10 pounds treated at the 1.0-percent level contained 0.83 percent endrin. Clearly, the coating treatments did not allow application of all endrin added to the seed. This is probably true with all coating treatments. The endrin content of seed treated with the same amount of the chemical will always vary depending mainly on kind and level of inactive ingredients added, equipment used, and accuracy in measuring the endrin and treating the seed.

Endrin content of 1.0 EC seed decreased slightly by helicopter dissemination, but seed consumption by mice did not change significantly. Whether similar results would be obtained with other commercially coated seed and other helicopters with different disseminators is not known.

The EDIa seed prepared in experiments 3 and 6 contained 0.39 and 0.45 percent endrin, respectively. The average endrin content of this impregnated seed, therefore, was somewhat lower than the recommended 0.5-percent level and approximately half that found on the 1.0-percent coated seed. The

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[5/] Data on file at the Forestry Sciences Laboratory, Olympia, Wash.

chemical was distributed on and in the seedcoat and in the "endosperm." Highest endrin concentrations were in seedcoats, indicating a tendency for accumulation of the chemical in this tissue. Although amounts of endrin in "endosperms" were very small, the mere presence of the chemical inside the seed is significant. It shows conclusively that seed were impregnated with endrin and that it may be possible to introduce other chemical protectants into the seed without impairing viability.

Effectiveness of treated seed against mice varied by treatment. The 1.0 EC treatment was approximately twice as effective as the 0.5 EC coating, which was consistently the least effective of all treatments. Since endrin in the 0.5 EC seed was at the "recommended" level, and in absence of other published data on the treatment for comparison, the basis for the recommendation is rather difficult to understand. Although the original treatment (Anonymous 1956) called for 0.5 percent endrin and 2 percent Arasan,[6/] the latter chemical has generally been eliminated from the treatment in the Pacific Northwest. Elimination apparently resulted from one field test which indicated that the chemical did not significantly improve protection even though the data showed many more seedlings produced when it was added (Dick et al. 1958). It is conceivable, therefore, that poor performance of the 0.5 EC seed in our experiments was due to the absence of Arasan. This view is supported by our unpublished data[7/] indicating that Arasan significantly increases the effectiveness of the 0.5-percent coating treatment. The endrin-Arasan combination has been successfully used for many years on southern pines (Mann 1968).

There were no differences in effectiveness among the endrin impregnation treatments. Apparently, the two solvents allowed similar amounts of endrin to enter the seed, and increasing the soaking time with either solvent probably did not affect the endrin content. All impregnations were also as effective as the 1.0 EC coating, even though impregnated seed contained about half as much endrin, as is indicated by analysis of the EDIa seed. This was probably due to the presence of the chemical on and in the impregnated seed and only on the surface with the coating treatment.

Consumption by mice of impregnated seed (EDIa) did not change significantly after helicopter dispersal or after repeated washings with water, indicating that the seed can withstand sowing operations and weathering in the field. Further, reduced feeding by mice on the impregnated "endosperms" presents additional evidence for success of impregnations and suggests that this method of treating seed would be more effective than coating.

CONCLUSIONS

Endrin is still the only chemical used for direct application on coniferous seed to protect it from rodents. Interest in the possibility of protecting seed by using truly repellent chemicals rather than toxicants remains high, and

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6/ Tetramethylthiuram disulphide (TMTD).
7/ See footnote 5.

screening for repellents continues. However, until a true repellent becomes available, the endrin treatment as now used should be improved. It is evident from our results that doubling the endrin concentration increases the effectiveness of the treatment, but we question this approach in view of the potential hazards involved because of very well-known toxicity of the chemical. Certainly, impregnation with endrin would be more desirable. The method would provide far better protection than is now possible with the 0.5-percent coating treatment, with an essentially similar endrin concentration. In addition, endrin losses from seed during and after sowing and consequent contamination of the forest environment would appear less likely from impregnated seed. However, because of expected higher cost and complexity of impregnating compared with coating, use of additives which may increase the effectiveness of coating should also be considered.

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1970
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Storing Endrin-Coated and Endrin-Impregnated Douglas-fir Seed

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M.A. Radwan and
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INTRODUCTION

In direct seeding, bad weather and other unfavorable conditions often necessitate storage of endrin-treated seed for periods of time ranging from a few days to several weeks. During this time, seed viability may be affected, and the effect will probably vary with the method of seed treatment and length and conditions of storage. To determine how to safely store endrin-treated seed, it is necessary to study effects of storage on the seed and establish the best possible storage conditions. Although the results of storing endrin-treated seed have been reported for the southern pine species (Jones 1963, McLemore and Barnett 1966),[1/] no information is available for any of the other important conifers, particularly Douglas-fir *(Pseudotsuga menziesii* (Mirb.) Franco).

Since 1956, the U.S. Bureau of Sport Fisheries and Wildlife has recommended protection of Douglas-fir and other coniferous seed with a coating of 0.5 percent endrin (Anonymous 1956). Recently, we compared endrin content and performance of endrin-coated and endrin-impregnated Douglas-fir seed and discussed the potential usefulness of impregnation (Radwan et al. 1970). In the present study, we have evaluated germination of coated and impregnated seed and performance of resulting seedlings after storage of treated seed at three different temperatures for periods ranging from 1 to 4 months.

MATERIALS AND METHODS

Two lots of Douglas-fir seed from Pierce County, Wash., were tested. The seed was collected in 1964 and 1965 and stored at -4° C. During the winter of 1968, samples were drawn from each lot and divided into four parts. One part of each sample was used as a control, and the other three parts were treated with endrin--one coating and two impregnations. Endrin 50-WP (50-percent wettable powder) from Stauffer Chemical Company[2/] was used for all endrin treatments.

One-half-pound batches of seed were coated with endrin. Concentration of the active ingredient was 0.5 percent by weight. The seed was wetted with a slurry of endrin in the adhesive Dow Latex 512-R, covered with aluminum powder, spread in a thin layer, and allowed to dry overnight under a hood.

[1/] Names and dates in parentheses refer to Literature Cited, p. 6.

[2/] Mention of chemical companies and their products does not represent endorsement by the Forest Service or by the Department of Agriculture.

Impregnation solutions containing 2 percent active endrin were prepared by dissolving endrin 50-WP in each of the two endrin solvents, 1, 2-dichloroethane (D) and trichloroethylene (T), and filtering out the inactive, insoluble ingredients of the powder. Seed was dried in a forced-air oven at 40° C. for 48 hours, enclosed in cheesecloth, dipped in the endrin solutions for 1 hour, and dried in a forced-air oven at 40° C. for 24 hours. This impregnation technique successfully introduced endrin inside seed (Radwan et al. 1970).

Each of the resulting eight treated and control seed samples (three treatments and one control per lot) was divided into 10 parts. Germination and production of seedlings were then determined immediately (no storage) and after storage in polyethylene bags at 20°, 4°, and -4° C. for 1, 2, and 4 months.

Four 100-seed replicates were germinated on perlite at 24°±1° C. after stratification for 21 days at 3° to 5° C., as prescribed in the standard test (Association of Official Seed Analysts 1965). Germinants were counted weekly, and tests were run for 28 days.

Production and growth of seedlings were studied concurrent with perlite germination tests. Two 100-seed replicates of stratified seed were planted in 4- by 4-inch pots about one-eighth inch deep in a mixture of equal parts soil, vermiculite, and peat moss. For germination and initial growth, pots were placed in a plant-growth chamber and watered daily. The chamber was set at 27° C. and 800 foot-candles (ft.-c.) of light for 20 hours per day and at 21° C. for 4 hours of darkness; relative humidity was about 70 percent. At the end of 28 days, the pots were transferred to another chamber and watered every 2 days. Temperatures were maintained at 27° C. during the day and 17° C. at night. Other growth conditions were 60- to 80-percent relative humidity and 1,200 ft.-c. of fluorescent-incandescent light on a 14-hour photoperiod. Seedlings were harvested and counted 50 days after planting. Roots and tops of seedlings were examined and ovendry weights of 10 randomly selected seedling tops from each pot were determined.

RESULTS

Before storage, germination and seedling production of untreated seed were higher for lot 1 than for lot 2 (table 1), indicating a better germination potential of this seed. Treatment with endrin by coating (0.5 EC) or by impregnation from the (D) solvent (EDI) did not affect germination of either lot on perlite or in soil. Impregnation with endrin dissolved in the (T) solvent (ETI), however, reduced germination on perlite but not in soil. Gross comparisons of dry weights and appearance of seedlings indicated no difference between the untreated lots. In addition, seedling growth from either lot of seed was not affected by any of the endrin treatments.

After storage, performance of all endrin-treated seed was almost equal to that of the untreated controls in soil. In addition, as with unstored seed, germination on perlite generally compared well with that in soil except with the

Table 1.--*Effect of storage on germination of endrin-treated and untreated Douglas-fir seed on perlite and in soil and ovendry weight of seedling tops produced in soil*

Seed treatment[1]	Seed lot 1			Seed treatment[1]	Seed lot 2		
	Perlite	Soil	Dry weight[2]		Perlite	Soil	Dry weight[2]
	Percent[3]		*mg.*		*Percent*[3]		*mg.*
NO STORAGE							
Control	88	79	29	0.5 EC	82	74	26
0.5 EC	86	83	32	Control	78	76	25
EDI	83	84	29	EDI	72	74	33
ETI	76	84	30	ETI	65	74	26
1-MONTH STORAGE							
Control (20° C.)	88	90	35	Control (-4° C.)	84	75	28
Control (4° C.)	87	83	27	Control (20° C.)	82	78	30
0.5 EC (4° C.)	86	86	26	0.5 EC (-4° C.)	81	72	29
EDI (4° C.)	86	83	26	Control (4° C.)	81	79	28
0.5 EC (-4° C.)	86	88	25	0.5 EC (4° C.)	76	73	31
Control (-4° C.)	85	85	26	EDI (20° C.)	76	74	32
0.5 EC (20° C.)	84	88	26	0.5 EC (20° C.)	74	68	32
EDI (20° C.)	83	86	27	EDI (-4° C.)	70	78	32
EDI (-4° C.)	82	87	28	ETI (-4° C.)	69	70	27
ETI (20° C.)	80	84	25	EDI (4° C.)	69	73	31
ETI (4° C.)	77	85	29	ETI (20° C.)	62	74	27
ETI (-4° C.)	77	83	26	ETI (4° C.)	62	69	30
2-MONTH STORAGE							
Control (-4° C.)	89	87	22	Control (-4° C.)	83	75	29
Control (4° C.)	88	83	28	Control (4° C.)	82	75	21
Control (20° C.)	88	86	25	0.5 EC (4° C.)	82	79	27
0.5 EC (20° C.)	88	85	22	0.5 EC (-4° C.)	81	77	26
0.5 EC (4° C.)	86	88	23	0.5 EC (20° C.)	80	73	21
0.5 EC (-4° C.)	85	86	26	Control (20° C.)	78	78	23
EDI (20° C.)	83	89	24	EDI (-4° C.)	74	73	27
EDI (-4° C.)	79	88	31	EDI (20° C.)	72	76	26
EDI (4° C.)	78	92	29	EDI (4° C.)	72	82	26
ETI (20° C.)	78	83	29	ETI (20° C.)	66	72	24
ETI (-4° C.)	77	86	25	ETI (-4° C.)	64	73	26
ETI (4° C.)	73	86	26	ETI (4° C.)	64	77	23
4-MONTH STORAGE							
Control (-4° C.)	90	82	28	Control (20° C.)	83	75	23
Control (20° C.)	89	89	24	Control (-4° C.)	80	78	28
Control (4° C.)	88	78	25	0.5 EC (4° C.)	80	75	26
0.5 EC (4° C.)	87	84	24	0.5 EC (-4° C.)	79	79	26
0.5 EC (-4° C.)	84	88	22	Control (4° C.)	78	73	26
EDI (-4° C.)	83	86	24	EDI (4° C.)	77	77	25
0.5 EC (20° C.)	80	82	25	0.5 EC (20° C.)	75	69	24
EDI (20° C.)	80	88	26	EDI (20° C.)	72	76	30
EDI (4° C.)	80	86	24	ETI (4° C.)	69	75	24
ETI (4° C.)	77	85	24	EDI (-4° C.)	68	78	23
ETI (-4° C.)	76	85	26	ETI (20° C.)	68	69	24
ETI (20° C.)	74	83	27	ETI (-4° C.)	65	77	23

[1] Control = untreated, 0.5 EC = endrin-coated at 0.5 percent, EDI = endrin-dichloroethane-impregnated, ETI = endrin-trichloroethylene-impregnated. Storage temperatures are shown in parentheses.

[2] Ovendry weights of tops per seedling are averages of 20 seedlings, 10 tops from each of two pots.

[3] Germination percents are averages of four and two replications each for perlite and soil tests, respectively. Means in the perlite column enclosed by the same line(s) do not differ significantly at the 5-percent level, with a modification of Tukey's test (Snedecor 1961).

ETI seed where results of the perlite tests were significantly lower.

Regardless of storage temperature, germination and seedling growth of endrin-coated and endrin-impregnated seed from both lots averaged nearly the same as those of unstored seed. This was evident at 1 month of storage and continued essentially unchanged throughout the entire 4-month storage period. However, with the endrin-coated seed of both lots, germination in most perlite and soil tests, when seed was stored at 20° C. was slightly lower than that of seed stored at the colder temperatures, indicating that cold storage might be more suitable for such seed.

Untreated and treated seed germinated rapidly both on perlite and in soil. Seedlings began to emerge from the soil by the end of the first week after seeding, and rate of emergence within each storage period was about the same regardless of lot, treatment, or storage temperature. Similarly, based on the proportion of total germination occurring on perlite within the first 2 weeks of each test, germination rate of the individual treatments did not vary with storage or temperature throughout the 4-month storage period. However, the treatments consistently showed different trends and were somewhat slower in germination than the controls. Thus, over all the temperatures and storage periods and based on the 2 weeks' germination of the controls, average rates for the 0.5 EC, EDI, and ETI treatments, respectively, were 97, 82, and 85 percent for lot 1, and 98, 78, and 76 percent for lot 2.

DISCUSSION

During many years of coating Douglas-fir seed with endrin, many forest managers in the Pacific Northwest have assumed that (1) endrin reduces germination to some extent, but reductions are tolerable in view of anticipated protection, and (2) the safest way to store treated seed is to place it under the same subzero temperatures recommended for untreated seed. Results of this investigation do not substantiate these assumptions. Using two seed lots, we found that coating with endrin at the recommended 0.5-percent level did not inhibit seed germination on perlite or in soil. Likewise, endrin-coated seed (0.5 EC) withstood storing satisfactorily for 4 months whether it was left at room temperature, refrigerated at 4° C., or placed at subzero, although seed stored at the colder temperatures showed better total germination in most tests. Obviously, it is impossible to identify conclusively the factor(s) responsible for these results. However, we suggest that drying the seed thoroughly after treatment and storing treated seed in moisture-proof containers were major contributing factors. The adverse effect of high moisture on storing coniferous seed is well known (Barton 1954). In addition, our unpublished data[3/] show that germination of undried seed was reduced by 15 to 30 percent during 2 months of storage at 4° C.

[3/] Data on file at the Forestry Sciences Laboratory, Olympia, Wash.

In the evaluation of results for coated seed, it should be noted that the endrin-coating treatment studied involved use of latex adhesive and aluminum coloring. Also, treated seed did not contain Arasan, which was eliminated from coating treatments in the Pacific Northwest in the late fifties because it inhibited germination slightly and did not seem to increase the effectiveness of endrin (Dick et al. 1958). It is not known whether results similar to those obtained in this study are possible when other coating treatments in which Arasan or different adhesives and coloring materials are used.

A recent investigation (Radwan et al. 1970) outlined methods for impregnating Douglas-fir seed with endrin and discussed germination, biological activity, and endrin content of impregnated seed. Results of the present study confirm previous observations that performances of unstored impregnated seed from the EDI and ETI treatments were, respectively, similar to and somewhat less than that of coated seed. The data also indicate that, as with coating, germination of impregnated seed remained essentially unchanged during storage for up to 4 months. This performance suggests that endrin solvents, especially 1,2-dichloroethane used for the EDI impregnation treatment, did not have serious adverse aftereffects on the seed and that endrin remaining on and inside the seed was not detrimental during storage.

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Application of endrin to Douglas-fir seed by coating at 0.5 percent or by soaking in endrin-dichloroethane solutions did not inhibit germination or seedling growth. Impregnation with endrin dissolved in trichloroethylene, however, reduced germination on perlite but not in soil. Regardless of storage temperature, germination and seedling growth of endrin-coated and endrin-impregnated seed after storage for up to 4 months was nearly the same as those of unstored seed.

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1970
USDA Forest Service Research Paper PNW—96

EFFECT OF SHADE ON GERMINATION AND GROWTH OF SALMONBERRY

by ROBERT H. RUTH

acific Northwest
orest and Range Experiment Station Portland, Oregon
orest Service · U.S. Department of Agriculture

INTRODUCTION

Salmonberry *(Rubus spectabilis* Pursh.), which forms a major component of shrubby vegetation in coastal areas, occurs mainly west of the Cascade Range in Oregon and Washington, south to California, and north to Alaska. Its preferred habitat is along streams and on benches and moist slopes. Salmonberry is especially common under red alder *(Alnus rubra)* and frequently is found under mature to overmature conifer stands. Following timber harvest, it often develops into dense thickets and delays or prevents forest regeneration.

Literature on salmonberry includes botanical descriptions *(1, 7, 13)*, [1/] reports on habitat preferences and associated species in local floras and plant community classifications *(2, 5, 18)*, [2/] [3/] silviculture articles about its competition with conifer seedlings *(4, 6, 11, 12, 17)*, and reports on control by herbicides *(9, 10)*. Isaac *(8)* observed the vegetative cover on 15 logged areas in the Douglas-fir *(Pseudotsuga menziesii)* region of western Oregon and Washington and found that salmonberry cover increased from 1.1 percent soon after logging and slash burning to 2.7 percent 8 years later. Frequency on his study plots increased from 14 to 43 percent in the first 5 years.

This report describes salmonberry development under various shade levels in the forest and in a forest opening. Data were collected during silvicultural studies of conifer seedling establishment on the same plots. [4/]

[1/] Italic numbers in parentheses refer to Literature Cited, p. 9.

[2/] Sharpe, Grant William. A taxonomical-ecological study of the vegetation by habitats in eight forest types of the Olympic rain forest, Olympic National Park, Washington. 1956. (Unpublished doctoral thesis on file at Univ. Wash., Seattle.)

[3/] Bailey, Arthur Wesley. Characterization of selected plant communities within the Tillamook burn in northwestern Oregon. 1963. (Unpublished master's thesis on file at Oreg. State Univ., Corvallis.)

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SALMONBERRY CROWN COVER

Observations of salmonberry were begun in the spring of 1956 on a 12-acre tract on the central Oregon coast 5.5 miles from the Pacific Ocean. The 113-year-old timber overstory of Sitka spruce *(Picea sitchensis)* western hemlock *(Tsuga heterophylla)* and Douglas-fir had been thinned 9 years earlier to about 80-percent canopy closure. A second partial cutting, the beginning of a shelterwood harvest cut made in the summer of 1956, reduced canopy closure to a fairly uniform 60 percent. Salmonberry crown cover under the timber stand was estimated on a grid of 124 1-milacre plots, with cover interpreted as the vertical projection of a polygon drawn around the undisturbed canopy. Only the dominant canopy not overtopped by other shrubs or herbaceous plants was included in the estimate. Observations were made prior to the second partial cutting and periodically during the next 7 years.

Salmonberry cover increased following reduction of the forest overstory. It was 3.1 percent in the spring of 1956 just prior to the second partial cutting. The cutting operation reduced it to 1.1 percent, largely through mechanical damage. There followed a consistent expansion of salmonberry crowns, with cover reaching 14.6 percent 7 years later (fig. 1).

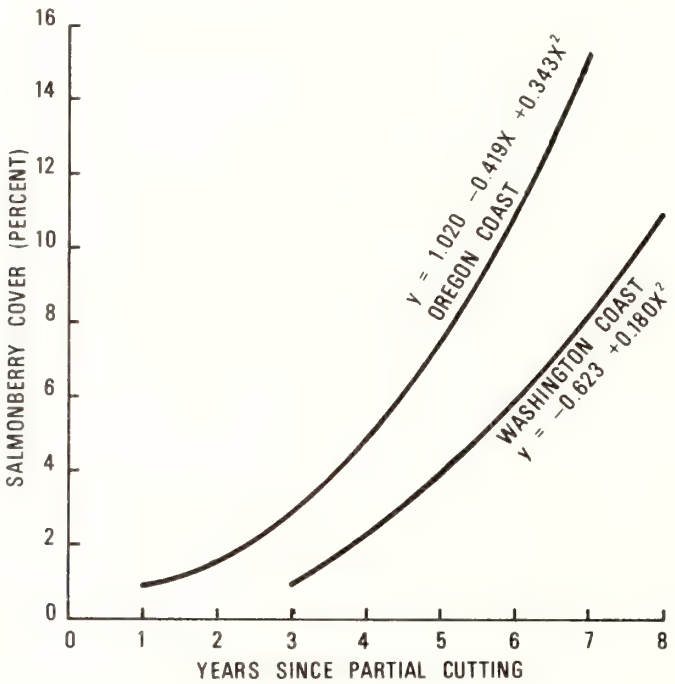

Figure 1.--Regressions of salmonberry crown cover on years since reduction of the forest overstory, by location.

A second study was begun on the Washington coast in the summer of 1960 on a 67-acre tract about 10 miles inland. A 58-year-old timber stand of almost pure western hemlock was divided into 12 treatment areas, and each stand was partially cut to leave a different basal area per acre. The cuttings, which were part of a shelterwood harvesting schedule, were made in two stages, the first in 1960-61 and the second in 1964-65. Considerable blowdown occurred in October 1962, and this was salvaged during the 1964-65 cutting. Basal areas remaining after the second cut ranged from 20 to 159 square feet per acre. Salmonberry crown cover was measured on 24 to 26 1-milacre plots established systematically on a central acre within each treatment area. Crown cover was estimated as before, but this time crowns of all salmonberry plants were included, even if they were overtopped by other vegetation. Periodic measurements were made through 1968.

Salmonberry cover again increased after partial cutting (fig. 1).

SALMONBERRY GERMINATION AND ESTABLISHMENT

Method

A third study was established in 1963 under a 120-year-old Sitka spruce, western hemlock, and Douglas-fir stand on the central Oregon coast. The timber had been thinned 1 to 2 years previously along four lines of plots to provide gradual decrease in overstory density and increase in solar radiation reaching the forest floor from plot to plot along each line. A total of 89 scarified 1-milacre plots were established at approximately 27-meter intervals along the lines. Plots that fell on slopes over 30 percent, in creek bottoms, or on roads were rejected. Scarification was done by tractor and bulldozer in September 1963. All ground vegetation was removed, but as much topsoil as possible was left. The northwest quadrant of each milacre was leveled with hand tools March 11-12, 1964, and a 30-centimeter-square wooden frame installed with about 1 centimeter of the edge protruding above the soil level. A supplemental group of 10 plots was installed in a nearby clearcut area. Both installations were completed in March 1964. Salmonberry seedlings that germinated inside subplot frames were counted periodically until September 22, 1965.

Additional subplots were established under the timber stand on the northeast quadrant of 43 of the milacre plots on May 14, 1964. The procedure was similar, except that bronze window screen, rather than a wooden frame, was used around the subplot, and hardware cloth was placed over the top until July 16 to keep out rodents. Supplemental plots again were established in the clearcut. Seedlings germinating before May 14 were destroyed during subplot establishment. During April 15-21, 1965, 89 additional subplots were installed in the southeast quadrant of the milacre plots and 10 more in the clearcut, using screen around the plot boundary and hardware cloth covers. The covers were removed May 19 and seedlings counted periodically until fall.

None of the plots was seeded with salmonberry seed. Slope was a fairly uniform 10 percent to the north. Variation due to competing understory vegetation was reduced by the scarification procedure. Two plots were destroyed by windthrown trees during the study.

Radiation reaching the milacre plots was measured chemically using a solution of anthracene, $C_6H_4CH{:}C_6H_4{:}CH$, in benzene, C_6H_6 *(16)*. Calibration was with a Moll Gorczynski solarimeter. Anthracene vials were exposed August 5, 1965, which was a clear day; August 26, 1965, which was partly cloudy; and September 8-10, 1965, during cloudy weather. Additional vials were exposed simultaneously in the nearby clearcut area to permit expressing radiation under the timber as a percent of that in the open. Numbers of salmonberry seedlings on the plots were converted to a per-acre basis and related to radiation through regression analysis.

Earlier measurements of soil moisture in the study area in the 0- to 15- and 15- to 30-centimeter depth classes had shown that soil moisture tension did not get above 15 atmospheres, indicating that soil moisture was continuously available to plants. By 1965, however, general observations of surface drying between summer showers indicated that moisture might indeed have been limiting near the soil surface where initial radicle penetration was taking place. Precipitation totaling 9 millimeters fell August 19, 1965, and this was followed by a slow drying out of surface soil. Samples were collected on September 9, 1965, at four depths along one line of milacre plots and in the clearcut. Plot size was 25 centimeters square, and sampling depths were 0- to 2-centimeter by 0.5-centimeter increments. Soil moisture percent was related to radiation by regression analysis with covariance analysis used to test for significant differences among depth classes. A composite sample was analyzed in the laboratory to determine moisture percent at 15 atmospheres soil moisture tension.

Number of Seedlings

Large numbers of salmonberry seedlings became established on the scarified seedspots (table 1). Almost one-half million seedlings per acre were observed on the wood-framed seedspots July 16, 1964. Only one of the 87 seedspots examined failed to produce at least one salmonberry plant by this date. Additional seedlings germinated in the spring of 1965, reached a maximum about the first of May, slowly declined in numbers during the summer, then increased again on both the wood-framed and screened seedspots after the beginning of the fall rains in September. Second season germination was only about 6 percent of that occurring the first season.

On the screened seedspots established April 15-21, 1965, germination did not begin until after May 24 and maximum number of seedlings per acre was only 14,680; there was no increase in seedling count in September (table 2).

Table 1.--*Salmonberry seedlings on 1964 scarified seedspots by examination date, type of plot, and cover class*

Examination date	Wood-framed seedspots		Screened seedspots	
	Under timber	In open	Under timber	In open
	Number per acre			
1964 germination:				
June 25-26, 1964	493,760	146,200	368,430	2,080
July 16, 1964	495,540	111,800	240,670	590
Apr. 9-12, 1965	267,300	--	42,610	0
1965 germination:				
Apr. 9-12, 1965	2,700	--	8,910	--
Apr. 28-May 3, 1965	16,200	0	27,710	0
May 19-24, 1965	8,900	0	14,860	0
June 8-9, 1965	4,450	0	5,940	0
June 30, 1965	4,450	0	2,970	0
Aug. 11-12, 1965	3,560	--	2,970	--
Sept. 22, 1965	10,680	--	14,860	--

Table 2.--*Salmonberry seedlings on scarified seedspots established in 1965, by examination date and cover class*

Examination date	Under timber	In open
	Number per acre	
May 19-24, 1965	0	0
June 8-9, 1965	2,940	0
Aug. 11-12, 1965	14,680	--
Sept. 22, 1965	5,870	--

Seedspots in the clearcut area which were exposed to full solar radiation were in a much less desirable environment for salmonberry establishment than those under the forest canopy (tables 1 and 2). The highest number of seedlings was on the wood-framed seedspots June 25-26, 1964. There was a reduction of almost 25 percent by July 16, with no seedlings surviving to the following April and no second-season germination. No seedlings became established on the exposed seedspots established in 1965.

Shade Effects

On the scarified plots under the forest canopy, solar radiation accounted for only a small part of the variation in seedling establishment. On the screened seedspots, numbers of seedlings decreased significantly with increasing radiation at both 1964 examinations (fig. 2). However, radiation accounted for only 13 to 16 percent of the variation, and the relationship was no longer significant when measured the following April after winter mortality.

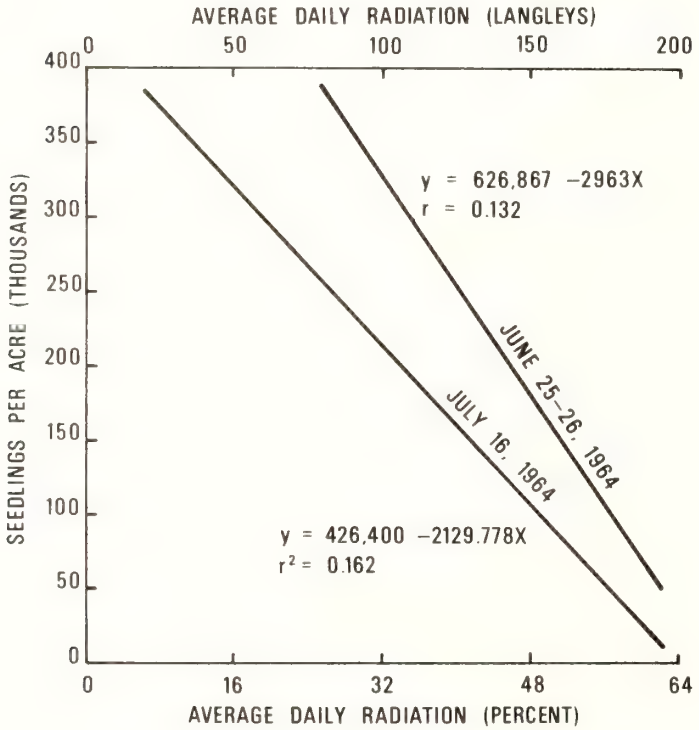

Figure 2.--Regressions of salmonberry seedlings per acre on radiation by examination date, screened seedspots.

On the wood-framed seedspots, the sample was larger, but no significant relationship between numbers of seedlings and radiation was found for either 1964 observation. When examined the following April, an increase in number of seedlings with increasing solar radiation was significant at the 5-percent level. Apparently overwinter mortality had been greater at the lower radiation levels. New seedlings becoming established the second season followed the pattern on the screened seedspots and showed a slight, but significant, decrease with increasing radiation (fig. 3). In these analyses only 6 to 8 percent of the variation in numbers of seedlings was related to radiation.

Soil moisture measurements by half-centimeter depth classes on September 9, 1965, showed a highly significant difference in moisture percent among the depth classes, and in all classes a highly significant decrease in soil moisture with increasing radiation. Soil moisture tension in the composite sample reached 15 atmospheres at 41.4 percent moisture. Taking this as an estimate of the wilting point, the soil moisture curve for 0- to 0.5-centimeter depth passed below this level where radiation averaged 100 Langleys per day, or 32 percent of radiation in the open. The 1.5- to 2.0-centimeter curve did not do so until radiation averaged about 195 Langleys per day, or about 60 percent of radiation in the open.

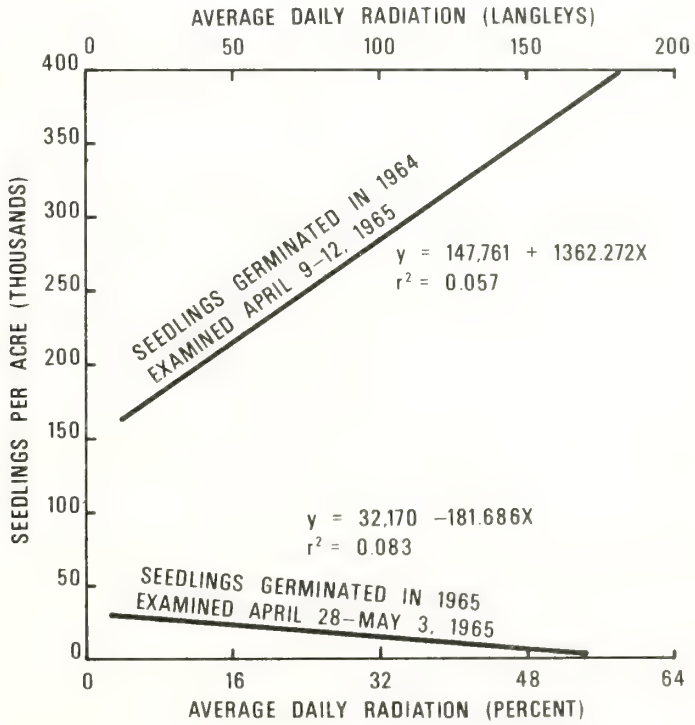

Figure 3.--Regression of salmonberry seedlings per acre on radiation by examination date, wood-framed seedspots.

DISCUSSION

It seems a reasonable hypothesis that large numbers of viable salmonberry seeds are present in the forest topsoil under coastal forest stands. The seed in our study did not come from a new crop, because none ripened between scarification in September and the prolific salmonberry germination the following spring. Carrying seed from plot to plot on the bulldozer or on our boots or hand tools was a possibility, but the distribution of new plants seemed too uniform for that. Also, an occasional strip of two or three plots had no seed-bearing salmonberry plants nearby, so any soil containing salmonberry seed would need to have been carried a considerable distance. Most seedlings were first observed in the cotyledon stage, attesting to their origin from seed. Depth of scarification ranged mostly from 5 to 15 centimeters into the mineral soil, indicating viable seed may have been present throughout this range. Frequent burrowing by moles (*Scapanus* spp.), which are common insectivores in the area, could account for this distribution. Research with other species has shown that seed can remain viable in the soil for long periods of time *(3, 14, 15, 19)*. The importance of salmonberry to coastal forest ecology and silvicultural practice warrants further examination of seed storage in the forest topsoil.

Salmonberry demonstrated a tolerance of heavy shade. In the coastal Oregon study, one seedling survived its first season on a scarified plot which received an average of only 7.2 Langleys per day, or 2.3 percent of radiation in the open.

Solar radiation received under the forest canopy ranged up to almost 70 percent of radiation in the open, and as far as first-year seedling establishment was concerned, the shade level had little effect. The significant relationships that were found showed decreasing numbers of seedlings with increasing radiation (figs. 2 and 3). But the coefficients of determination were low, indicating that little of the variation was explained by radiation alone. That some shade is important, however, was demonstrated by better survival under the forest canopy as compared with the clearcut (table 1). In the open, and to a lesser extent with increasing shade from the forest canopy, the soil surface dried out during short periods of clear weather. Perhaps penetration of the radicle into the soil could not keep pace with receding soil moisture so that drought rather than too much radiation limited seedling establishment. On the other hand, established salmonberry plants with their roots in permanently moist soil seem to do best in full light. The densest salmonberry thickets are found in forest openings rather than under timber stands.

The increase in salmonberry crown cover following reduction of the forest overstory was expected. Most of the increase was in crowns of existing plants, but some new plants were involved, especially in the Washington study. Cover averaged more under the Oregon forest stand, probably because the stand was older and had been lightly thinned 9 years before observations began. The timber stand in Washington was more dense, with salmonberry in the understory covering less than 0.1 percent of the soil surface at the start of the study. Here

it took salmonberry cover about 3 years to reach 1 percent; then the rate of increase was similar to the Oregon area (fig. 1).

Repeated thinnings surely will lead to increased cover, so salmonberry seems destined to remain an important part of coastal forest communities. To the extent it competes with tree seedlings, its control will need to be an essential part of silvicultural practice.

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GPO 997-235

1970

USDA FOREST SERVICE RESEARCH PAPER PNW-9

Slash Fire Atmospheric Pollution

by

Fritschen, Bovee, Buettner, Charlson, Monteith, Pickford, Murphy, and Darley

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1. INTRODUCTION

In the Pacific Northwest, as in many other parts of the country, burning is the standard method for disposal of undesirable waste including logging debris and agricultural residue. About 81,000 hectares (200,000 acres) of logging slash are burned annually west of the Cascade Range in the States of Washington and Oregon. In addition, 101,000 hectares (250,000 acres) of grasslands are burned in Oregon.[1] Many other forms of residue are also disposed of by burning.

Burning of waste contributes unknown quantities of gases and particulates to the atmosphere which may result in local or areawide pollution. In many cases, burning presently appears to be the most practical and economical way of slash disposal. It is hoped that in the future more complete utilization of logging residues will eliminate the necessity of burning. But until then, prescribed burning may be the only way to reduce fire hazard and thus the possibility of sustained pollution from wildfires occurring during periods of limited ventilation or low inversions.

Contribution of burning of agricultural wastes to air pollution has been studied in California by McElroy,[2] Bell and Waggoner (1961),[3] Feldstein et al. (1963), and Darley et al. (1966), but only limited information has been available on the part played by slash disposal. In addition to our project, current research on the subject is being conducted at Oregon State University and Washington State University in cooperation with the Northern Forest Fire Laboratory at Missoula, Montana. The objectives of these studies are similar, but the methods, fuels, and environmental conditions are quite different (Fritschen 1967). This parallel research is justifiable because of the complexity of the problem and because techniques found optimum for minimizing pollution in one geographical region may not be universal.

[1] Metric units are used in this report; see 9.2 for conversion factors.

[2] McElroy, G. Agriculture and air pollution. 1959. (Unpublished report, Univ. Calif. Ext. Serv., Berkeley.)

[3] Names and dates in parentheses refer to References p. 39.

Feldstein et al. (1963) state the general rule of thumb that the higher the combustion temperature and the longer the residence time at that temperature, the more complete the combustion will usually be if there is enough oxygen present. They offer data from single- and multiple-chamber incinerators which support the rule of thumb. However, local pollution is a function of incomplete combustion, total amount of material consumed, and completeness of dispersion. Furthermore, the primary objective of slash burning is not complete consumption, but to (1) expose sufficient mineral soil for regeneration, (2) reduce fire hazard, and (3) reduce undesirable species. Since fire hazard – especially ignition potential, rate of spread, and initial buildup – is directly related to the amount and percentage of fine fuel present, the objectives of slash disposal and minimum pollution may be achieved by a hot fire of sufficient duration to consume the fine fuels under favorable conditions for atmospheric dispersion. The hot fire, under field conditions, will provide the additional buoyant lift needed for dispersion.

2. OBJECTIVES

The primary objective of this project was to investigate the current practice of slash burning in relation to air pollution. The hypothesis tested was that incomplete combustion and, consequently, greater emissions result from low-temperature fires. Low fire temperatures are usually associated with broadcast burns because of relatively low discontinuous available fuel loading and slow ignition techniques with a slow buildup of fire intensity. A "safe" fire is an implicit management objective. Conversely, piled slash, with higher available fuel loading and arranged so that oxygen was not limiting, could be expected to burn more completely and at higher temperatures, producing less pollution.

The results of the field tests were to be compared with laboratory burns, with respect to burning characteristics and gaseous and particulate emissions, to determine whether the salient features of a field test can be modeled.

3. EXPERIMENTAL METHODS

3.1. Experimental Sites

Most of the research experiments of this project were carried out at the Charles Lathrop Pack Experimental Forest of the University of Washington. This area is located at the southern boundary of Pierce County, Washington, 35 kilometers south of Puyallup, 45 kilometers southeast of Tacoma, 48 kilometers southeast of Olympia (fig. 1). The broadcast burn (3.1.1)[4] and the pile burn (3.1.2) were conducted on a portion of Pack Forest near the confluence of the Mashel and Nisqually Rivers, about 1 kilometer downstream (north) from the mouth of a 152-meter-deep canyon (fig. 2). The area selected for the burn is on an alluvial terrace at an elevation of 229 meters, 76 meters above the river. The land slopes gently to the northwest. To the south and east are deeply dissected foothills of Mount Rainier. To the north and west, the topography is more gently dissected outwash and ground moraine, deposited during the Vashon ice age. Vegetation in the area regenerated naturally after a forest fire in the 1920's and consists of Douglas-fir with bracken fern, salal, trailing blackberry, hopclover, geranium, and other herbs and short shrubs.

3.1.1. BROADCAST BURN

Twelve hectares of Douglas-fir and associated species were clearcut during the spring and summer of 1967. The south 7.45 hectares of the 12.1-hectare area were burned in a broadcast burn on June 25, 1968. The area was center-fired with an electrical ignition system (see 3.3.1).

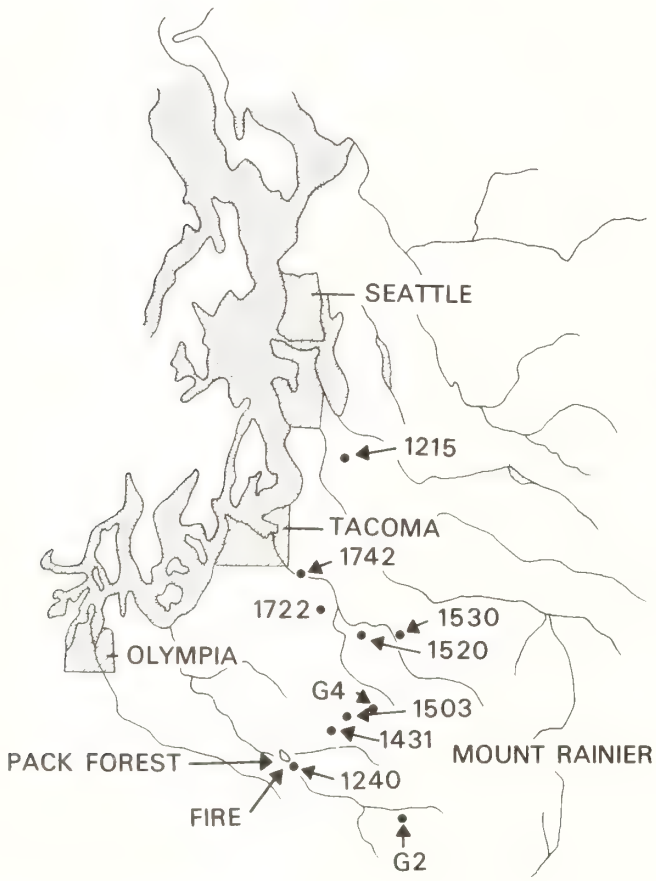


Figure 1. – Pack Forest and neighboring urban centers. Times (i.e., 1215) indicate location of aerial soundings and G2 and G4 indicate gas sample locations, discussed in chapter 3.

[4] Chapter 3, section 1, subsection 1.

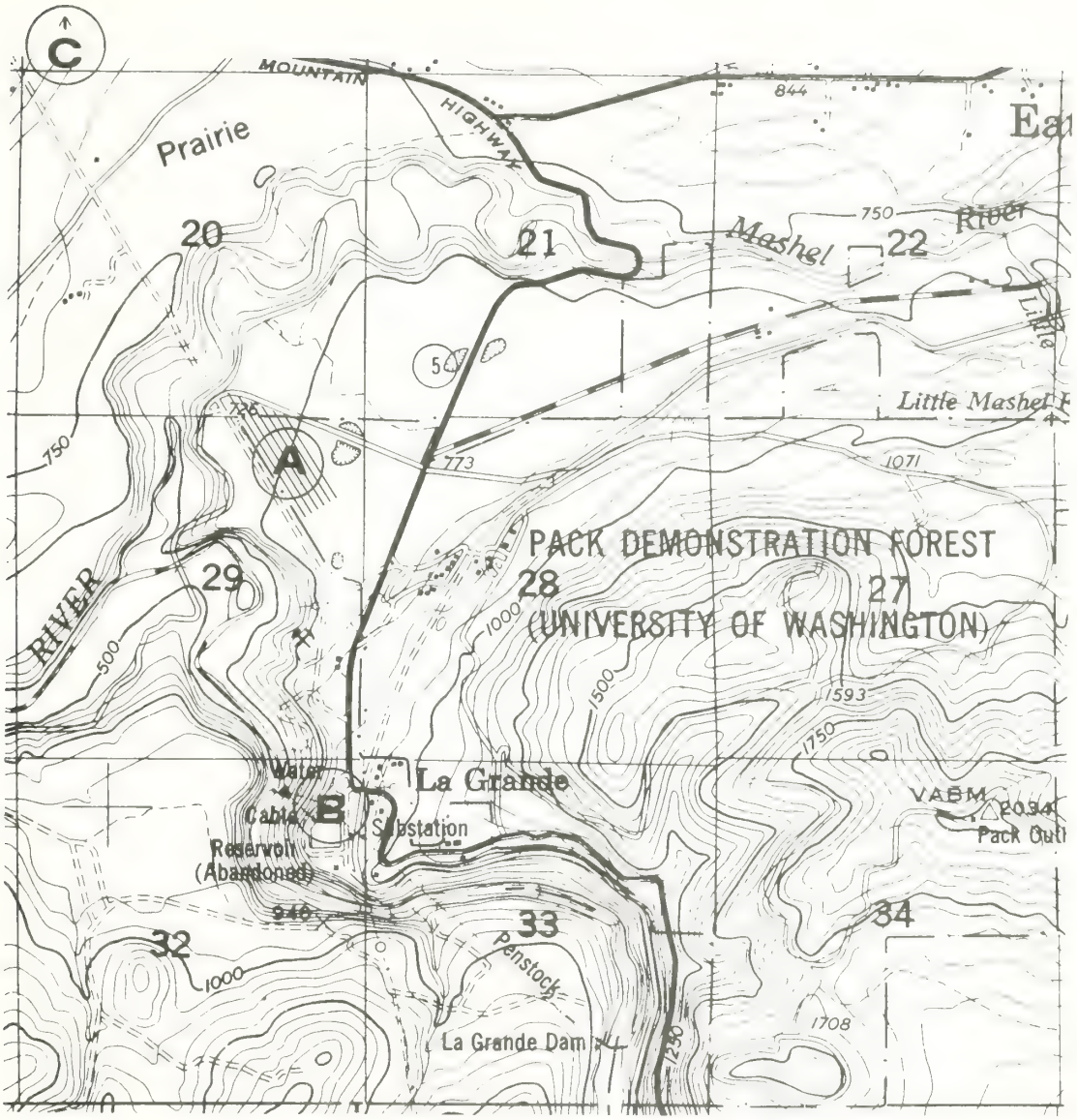


Figure 2. — Topography of Pack Forest area. The experimental site is at A and the remote camera sites are at B and C. Note that elevations are in feet m.s.l.

3.1.2. PILE BURNS

Two cone-shaped piles, each 6 meters in diameter at the base and 3 and 6 meters in height, respectively, were prepared by hand stacking from approximately 0.81 hectare of slash on the northern portion of the 12.1-hectare clearcut. These piles consisted mainly of larger material, i.e., material greater than 2 centimeters in diameter, and were burned on July 11, 1968.

3.1.3. CANADIAN FIRE

The Canadian Department of Forestry and Rural Development, under the leadership of Bob Henderson, Fire Research Officer, Victoria Laboratory, Victoria, British Columbia, was conducting research on prescribed burns in an area north of Mission City, British Columbia. Several attempts were made to monitor the smoke from these prescribed burns. However, the unseasonably wet

weather and logistics problems prevented monitoring of more than one fire. The monitored fire did not burn as planned and the data obtained are not worth inclusion in this report.

3.1.4. LABORATORY FIRE

Samples of Douglas-fir *(Pseudotsuga menziesii)*, western hemlock *(Tsuga heterophylla)*, and western redcedar *(Thuja plicata)* slash collected from Pack Forest area shortly after the field burns, were sent to Dr. Ellis Darley[5] for laboratory analysis of combustion products. The results of these laboratory burns were compared with those obtained under field conditions to determine the necessity for further field studies of pollutant emissions from slash fires. The system utilized for combustion and analysis is described by Darley et al. (1966).

3.2. Fuel Survey

3.2.1. FUEL WEIGHT

The quantity of fuel on the 7.45 hectares used for the broadcast burn was estimated with a line intersect method similar to that used by Beaufait.[6] The 89 sample plots were established and measured during the summer of 1967. Postponement of the experiment to the summer of 1968 necessitated resurvey of the original plots prior to the burn. Material remaining on the ground after the burn was estimated by the same method.

Sample points were established in a grid on 30-meter centers by use of 1-meter concrete reinforcing rods driven vertically into the ground. Vertical transects were established at each sample point by a horizontal meter stick mounted on top of a staff compass at the reinforcing rod point. The direction of the meter stick was chosen as follows: 6 azimuths from 0° to 180° at 30° increments were assigned to the face of a die. The die was spun at each sample point and the meter stick was aligned to the corresponding azimuth with the compass. The ends of the vertical transect were located by a plumb bob dropped from the ends of the meter stick.

The total depth of slash was measured to the nearest centimeter at the ends and the middle of the meter stick. Exposure of mineral soil along the length of the transect line was visually estimated as percent of the line. Each piece of slash which intersected the transect was identified for species and classed as slash, brush, or duff. Each piece was counted into one of three size classes, 0 to 1 centimeter, 1 to 10 centimeters, and greater than 10 centimeters. The diameter of each log larger than 10 centimeters was measured to the nearest centimeter. Duff consisting of dried or decaying needles and twigs was measured to the nearest centimeter at each of three positions, ground level, midheight, and the top of the slash. The diameter of each piece of slash less than 1 centimeter was recorded on each of ten 1-meter transects. The diameter of each of these from 1 to 10 centimeters was recorded on four transects. These measurements were used to compute the average cross-sectional areas for these two size classes as shown in table 1. Samples of the various brush species were checked throughout the burned area. The average cross-sectional area was estimated at 0.071 square centimeter. The number of pieces of 0- to 1-centimeter and 1- to 10-centimeter material in all transects was multiplied by the average cross-sectional area of these diameter classes for an estimate of the total area in each class. The area of material greater than 10 centimeters in diameter was computed from the plot data. Depth of duff was averaged for all plots. These figures were used to compute the volume of fuel on the 1-meter-square area bisected by each transect:

$$V = 100\,C(\pi/2L)$$

where V is the fuel volume in $cm.^3 m.^{-2}$; C is the total cross-sectional area of the material in square centimeters; L is the total length of the transect in centimeters; and $\pi/2$ is the elliptical correction for the slash crossing the transect plane at other than right angles (Van Wagner 1968).

The resulting averages were used to compute the total fuel volume and weight on the 7.45 hectares as shown in table 2.

The bulk density of the duff taken from the burn area was found to be 0.04 gram per cubic centimeter ($g.cc.^{-1}$). The slash material was assigned a density of 0.40 $g.cc.^{-1}$, based on the values for ovendried Douglas-fir as given by "Wood Handbook" (USDA Forest Products Laboratory 1955).

The amount of material remaining after the June 25 fire was estimated on 22 plots by the

[5] Dr. Ellis Darley, Statewide Air Pollution Research Center, Riverside, Calif.

[6] Personal communication. Dr. William Beaufait, Northern Forest Fire Laboratory, Missoula, Mont.

Table 1.—*Calculation of average cross-sectional area for material in two diameter classes, broadcast fire, Pack Forest, June 25, 1968*

0- to 1-centimeter diameter class	Number of pieces	Total area	1- to 10-centimeter diameter class	Number of pieces	Total area
		Cm.^{2}			*Cm.*^{2}
0.1	186	111.4601	1	44	34.5400
.2	653	20.5042	2	10	31.4000
.3	265	18.7222	3	1	7.0650
.4	130	16.3280	4	2	25.1200
.5	63	12.3637	5	4	78.5000
.6	28	7.9128	6	0	
.7	21	8.0776	7	0	–
.8	16	8.0384	8	0	–
.9	15	9.5377	9	0	–
			10	0	–
	1,377	102.9448		61	176.6250
$c = \frac{102.9448}{1377} = 0.0748$ cm.^{2}			$c = \frac{176.625}{61} = 2.8955$ cm.^{2}		

Table 2.—*Weight and volume of fuels on the ground prior to broadcast burn, Pack Forest, June 25, 1968*

Size of material	Number of pieces	Total area	Volume per plot	Weight per plot	Weight for 7.45-hectare burn	
		Cm.^{2}	*Cm.*^{3}	*Grams*	*Metric tons*	*Short tons*
Duff	(5.53)[1]		55,300	2,212	164.79	162.0
0-1 cm.	15,435	1,154	2,038	815	60.72	59.7
1-10 cm.	653	1,890	3,337	1,335	99.46	97.9
10 cm.	34	6,330	11,147	4,459	332.20	326.9
Brush	1,559	110	194	78	5.81	5.7

[1] Average depth of duff on all plots.

same sampling methods. Exposed mineral soil was estimated on 45 plots as percent of transect length. Brush was unrecognizable as such and was included with the slash material. Density was assumed to be the same. Fuel in the 0- to 1-centimeter size class was almost completely consumed by the fire. The average cross-sectional area was assumed to be 0.5 square centimeter. The average cross-sectional area in the 1- to 10-centimeter size class was found to be 23.9 square centimeters on the basis of 24 measurements. The results are shown in table 3.

3.2.2. FUEL MOISTURE CONTENT

Samples of each type and diameter class of slash were collected from each sample point the day before the fire, because firing grenades were placed in the slash area the morning of the burn. Weather conditions affecting fine-fuel moisture were comparable on both days. These samples were stored in polyethylene bags at -5° C. until moisture content determinations could be run.

Moisture content determinations were to be made with a Carl Fisher apparatus; however, no satisfactory technique for handling milligram subsamples was found which would allow for the large intrasample variations in these samples. Consequently, moisture content determinations were made on a pilot basis by use of weight loss after drying at 105° C., weight loss after vacuum ovendrying, and toluene distillation. After the initial pilot runs, the vacuum oven technique was chosen as the best compromise between repetition and analysis time.

3.3. Ignition Techniques

3.3.1. BROADCAST FIRE

Since engineers participating in the study of the clearcut block burn were studying energy exchange, a quickly ignited fire with a high rate of energy release was desired, because one dominant convection column with basal air entrainment was required. A secondary factor affecting the ignition strategy was the large amount of green fuel present on the block because of the 1-year "layover" of slash. Green bracken fern, salal, trailing blackberry, hopclover, geranium, and other herbs and short shrubs made up a nearly complete green ground cover 25 to 60 centimeters tall. Considerable heat output would be necessary to overcome the high moisture content of this live fuel element.

An electrical ignition system with an areally distributed fuel booster was used to obtain the quick hot fire. This type of ignition and burning strategy is occasionally used on better planned prescribed burns in the forests of central and northern California and the Pacific Northwest[7] (Reifsnyder 1956; Schimke and Dougherty 1966). Because the fuel was sparse and discontinuous on the northwest one-third of the block, the experimental team decided to confine the burn to the southeasterly 7.45 hectares.

[7] See also: USDA Forest Service. Use of electric starters on Hobo Block 25. St. Joe National Forest. 1966. (Unpubl. report, St. Joe National Forest, St. Maries, Ida.)

Table 3.—*Weight and volume of fuels remaining after broadcast burn, Pack Forest, June 25, 1968*

Size of material	Number of pieces	Total area	Volume per plot	Weight per plot	Weight for 7.45-hectare burn	
		Cm.^{2}	*Cm.*^{3}	*Grams*	*Metric tons*	*Short tons*
Duff	(2.71 cm.)[1]		27,100	1,084	80.76	79.5
0-1 cm.	41	20.5	58	23	1.71	1.7
1-10 cm.	39	932.1	2,662	1,065	79.34	78.1
10 cm.	23	4,614.0	13,345	5,338	397.68	391.4

[1] Average depth of duff on all plots.

Four hundred and twenty ignition points were systematically located over the slash area. One central line of ignition points extended down the middle of the rectangular burning unit (fig. 3). Three rings of ignition points were also placed — the innermost ring 15 meters from the centerline; the middle ring, 45 meters; and the outside ring, 83 meters or 7.5 meters from the outside edge. The outer two rings were split into two separate circuits because of high accumulated resistance.

The circuits were wired in series (rather than parallel) because voltage force can be calculated more readily and because less wire is necessary which reduces the cost. An ohmmeter was used for constant field checks of resistance and continuity of circuits. A total of 5,486 meters of aluminum wire was used for the electrical circuits. Aluminum wire was used because it would melt at temperatures expected during the slash burn, and it would not have to be retrieved afterwards to prevent injury to test personnel or wildlife. A jellied fuel, identical to napalm, was used as the fuel booster package at each ignition point.

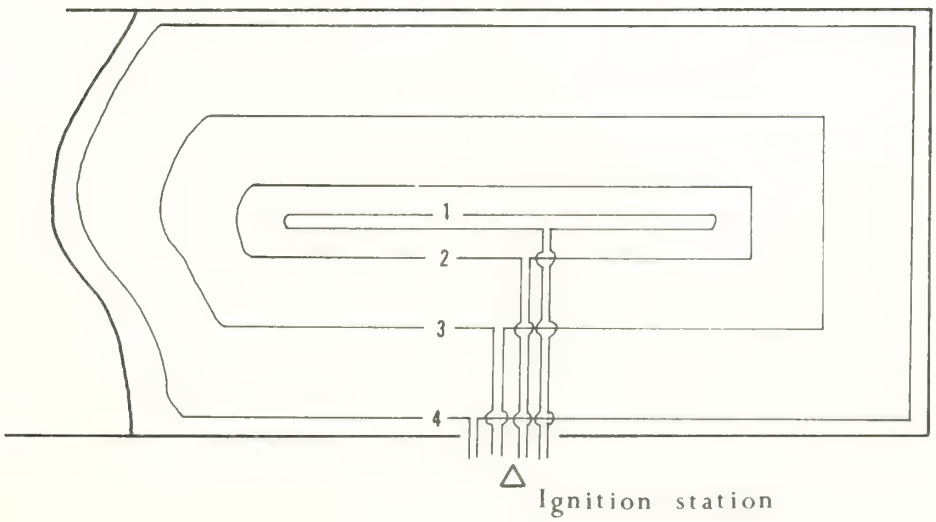
The central ignition line and the northwesterly end of the block were fired with 1.06-liter grenades. Greater heat output was judged necessary at this northwesterly location because of the large amounts of green fern, herbs, and brush with high, live-fuel moisture. Plastic packages filled with the fuel booster, called "blivets," 0.78 liter in volume, were used for all of the remaining ignition points. The thickened napalm was used because preliminary tests showed it to have the following advantages:

1. Easy to ignite.
2. Sustained, hot flame: 7×10^6 calories (28,000 B.t.u.) heat content per 453 grams (1 pound) and an approximate burning temperature of 770° C. (1,400° F.). Other fuel boosters in use (i.e., petroleum gels) have a heat value of approximately 4.5×10^6 calories (18,000 B.t.u.) per 453 grams and burning temperatures of 440° C. (800° F.) (Schimke and Dougherty 1966). The napalm fuel booster units burn longer (6-10 minutes) than any other incendiary device used in forest fire operations (Dell and Ward 1967).
3. The fuel will not flash off.
4. Manufacturers claim the fuel residue is not injurious to human or animal life.

A total of 249 kilograms of the jellied fuel was used. Black powder squibs and spitter fuses were the ignition source. A 50-cap condenser-type blasting machine was used as the power source.

The central circuit was ignited first. Then each ring or half ring was ignited 2 minutes apart with the peripheral ring ignited last. The firing strategy was planned to produce the central convection column and basal air entrainment required for the study.

Figure 3. — Electrical ignition plan of the broadcast fire on Pack Forest, June 25, 1968. Circuits 1, 2, 3, and 4, as shown, were fired in that order.



3.3.2. PILE FIRES

The piles were ignited around the base with standard drip torches filled with a 3:1 mixture of diesel fuel and gasoline.

3.4. Emission Analysis

3.4.1. SUSPENDED PARTICULATE MATTER

3.4.1.1. Ground sampling. – Particulate emissions were monitored continuously by high-volume, air samplers located near the downwind perimeter of the fire. Suspended particulate matter was collected on glass fiber, high-volume filter mats (MSA CT-75428).

The particulates from the high-volume filters were extracted with benzene in a Soxhlet extractor. The extract was analyzed by a gas chromatograph and mass spectrometer combination employing a 15 meter SE 30 column.

3.4.1.2. Airborne sampling. – Particulates in the smoke plume were determined as the light-scattering coefficient measured with an airborne version of the continuous integrating nephelometer developed under this grant (Ahlquist and Charlson 1968). The light-scattering coefficient and air temperature were measured and recorded simultaneously by means of a special digitizing circuit and a four-track portable tape recorder. Air pressure (altitude) was recorded on the third track and the fourth track was used for voice recording of the observations.

The resulting magnetic tape data from each sounding was plotted directly with a Leeds and Northrup XY plotter. These results were converted to micrograms per cubic meter following the method of Charlson et al. (1968) and plotted with potential temperature versus altitude.

3.4.2. CARBON MONOXIDE AND CARBON DIOXIDE

3.4.2.1. Broadcast fire

3.4.2.1.1. Ground sampling. – The air samples were taken at two locations: flame gas samples from the immediate vicinity of the flames and smoke samples at ground level near the downwind perimeter of the fire.

Two special sampling techniques were developed for this project, one for sampling flame gases and the other for sampling smoke on the ground without the benefit of electrical power.

Samples of flame gases from within the actual fire were obtained by a technician wearing an asbestos suit. The samples were collected in an evacuated 1,000 milliliter boiling flask fitted with a 90° connecting tube and a stopcock with a tapered ground-glass joint (Kimax 45000). These flasks were supported on a metal probe which also carried a thermocouple for measurement of the flame temperature.

The distribution of the gases downwind from the fire was mapped by use of the water displacement air sampler developed for this project.[8] This sampler was used primarily to determine the carbon monoxide and carbon dioxide concentrations. However, hydrocarbon gases were identified and measured from the samples taken with this device during the broadcast fire on June 25. Changing the samplers periodically during the course of each fire gave a time sequence of gaseous emissions throughout the fire. These samplers could be adjusted for a period ranging from 6 minutes to 2 hours and provided an automatic integration over the sample period. These samplers were located as shown in figure 4 for the June 25 broadcast fire.

Grab samples of smoke were obtained from the fire perimeter and also within the plume from the instrumented aircraft. These samples were collected by use of evacuated oxygen breathing tanks and a Mylar bag which was filled by means of a rubber squeeze bulb (Breysee and Bovee 1966).

Spot analyses of carbon monoxide concentrations were made with Monoxor Chemical Detector tubes. The concentration of hydrocarbon gases was also spot checked with a Johnson-Williams Combustible Gas Detector, Model SSP.

The concentrations of carbon monoxide and carbon dioxide were measured in the water-displacement air samplers by Beckman nondispersive infrared gas analyzers operated in series. The analytical train is shown in figure 5. Water vapor and particulates were removed by a Dryerite

[8] Pickford S., Charlson, R., and Buettner, K. J. K. A water-pump air sampler for use at remote sites. (In preparation for publication, USDA Forest Serv. Pacific Northwest Forest & Range Exp. Sta., Portland, Oreg.)

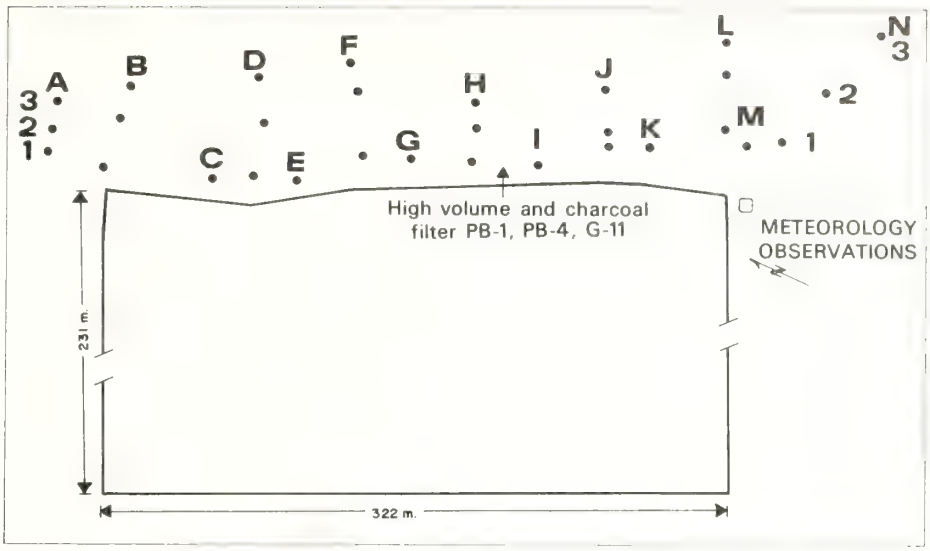


Figure 4. — Location of water-displacement air samplers, other samplers, and meteorological observations for broadcast fire, Pack Forest, June 1968. Sampling lines are numbered 1, 2, and 3, and locations on each line are represented by letters.

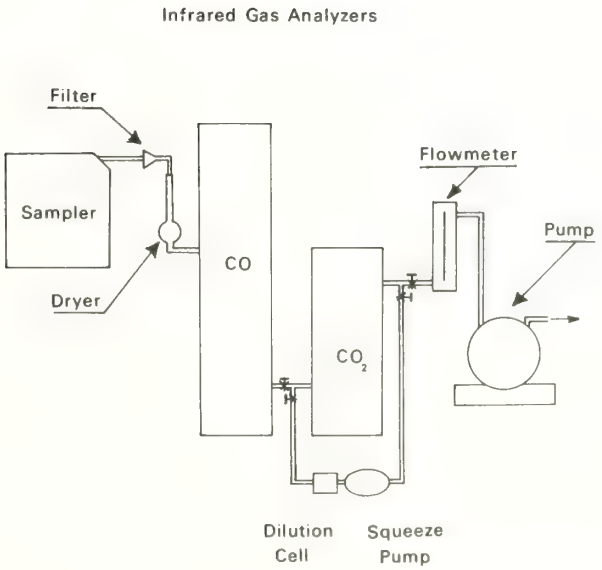


Figure 5. — Analytical train for CO and CO_2 analysis.

tube and a 41-millimeter glass mat in-line filter. The dried and filtered sample was analyzed for carbon monoxide concentrations on a Beckman 315, 0 to 100 p.p.m. (parts per million) long path, carbon monoxide analyzer. The outlet of this analyzer was connected directly to the inlet of the Beckman 215A, 0 to 600 p.p.m., short path, differential carbon dioxide analyzer using dry nitrogen in the reference cell. Varying the inlet control of the vacuum pump maintained the flow rates through the system at 50 milliliters per minute.

Gas samples were diluted when the carbon dioxide concentration exceeded 600 p.p.m. The dilution apparatus consisted of a 50-millimeter length of 76-millimeter tubing connected in series with a rubber squeeze bulb pump. The sample was shunted from the carbon monoxide analyzer through the dilution train, and when full, the train was closed. The carbon dioxide analyzer was then flushed with dry nitrogen, and the dilution system containing the sample was reconnected to both the inlet and the outlet of the analyzer. The nitrogen in the sample cell was mixed with the sample air by a squeeze pump. An accurate dilution factor was obtained by calibration of the dilution system with 370 p.p.m. carbon dioxide in air. This dilution factor was applied to the measured concentration to give the original concentration of carbon dioxide in the system.

The samples taken from within the fire were analyzed with the same system. A much higher concentration of carbon monoxide and carbon dioxide required a dilution factor of 83.331 which was obtained by replacement of the 76-millimeter tubing in the dilution train with a 19-liter carboy and operation of the dilution system in a closed path circuit through both analyzers. The dilution system was calibrated with dry nitrogen containing 250 p.p.m. carbon monoxide and compressed air containing 370 p.p.m. carbon dioxide.

The contents of the sample flask were at less than atmospheric pressure due to the difference between the collection and analysis temperatures. Each flask was brought to ambient pressure by the addition of dry nitrogen. The concentration of the diluted gas was measured with the analytical train, and the true concentration of the original gas then was calculated from the known flame temperature. By an assumption that the pressure change within the sampler was due entirely to the difference in temperatures, the correction equation simplified to:

$$Xt = \frac{(T_1)}{(T_2)} X_o$$

where, Xt is a true concentration, X_o the measured concentration, T_2 is the gas temperature at time of analysis in degrees kelvin, and T_1 is the flame temperature when sampled in degrees kelvin.

3.4.2.1.2. Airborne sampling. – Smoke samples were taken within the plume by personnel in the instrumented aircraft. These samples were analyzed for CO and CO_2 with a Beckman Ir-4 infrared spectrophotometer fitted with a 10-meter gas cell.

3.4.2.2. Pile fire. – Smoke samples from the plume of only one of the pile fires burned on July 11 were obtained by the water-displacement air samplers suspended in the plume about 12 meters above the ground. Lines thrown across the tight-wire were used to raise and lower the air samplers as shown in figure 6. The gas samplers were analyzed as described in section 3.4.2.1.1.

3.4.3. HYDROCARBON GASES

3.4.3.1. Broadcast fire. – Contaminants in several of the air samples were concentrated by freezeout at liquid nitrogen temperatures and analyzed by a combined gas chromatography-mass spectrometry technique (Bovee et al. 1966). A Varian-Aerograph Model 1200 gas chromatograph using the flame ionization detector was equipped with a 3.05-meter stainless steel Porapak Q column. Temperature was programed from 40° to 220° C., and the range of analysis extended from ethylene to xylene. A splitter placed just ahead of the detector directed part of the column effluent to a Perkin-Elmer Hitachi RMU-6D mass spectrometer. A mass spectrum was recorded for each chromatograph peak plus additional spectra for compounds not detected by the flame ionization detector. Hydrocarbon gases were also monitored continuously throughout the broadcast fire on June 25. These gases were collected on a charcoal filter which was operated from 1330 to 1800. The material collected on the charcoal was desorbed under vacuum, collected in a liquid nitrogen freeze trap, and analyzed by gas chromatography and mass spectrometry.

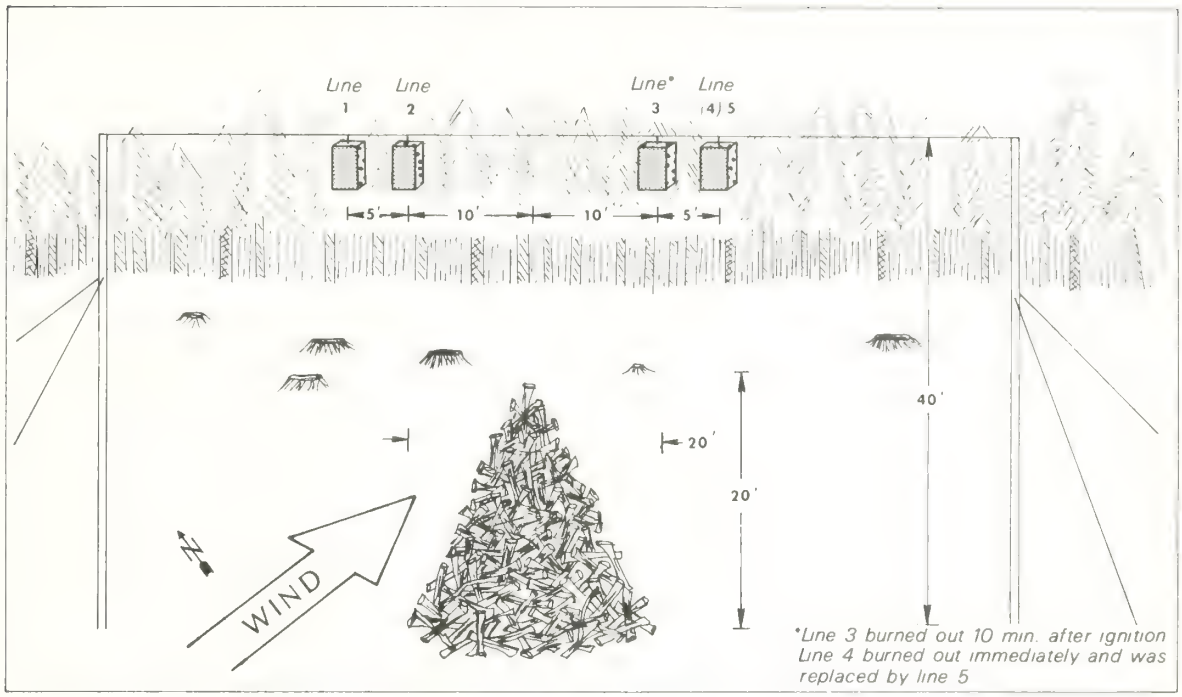


Figure 6. — Location of water displacement air samples for pile fires, Pack Forest, July 11, 1968.

3.5. Photography

3.5.1. BROADCAST FIRE

Closeup and distant photographs were taken for study of the action of the flames and the intensity of the fire and for study of the buildup and smoke migration. For the closeup pictures, a 16-millimeter movie camera was located at each of the four corners of the fire. The cameras were adjusted to take a frame every 10 seconds, viewing the fire at right angles from two sides, the north and the south.

The distant cameras were located 3.8 kilometers to the north and 1.4 kilometers to the south. These were 16-millimeter movie cameras adjusted to expose one frame every 10 seconds. In addition, another 16-millimeter movie camera was used to take continuous pictures of the fire development from the instrumented aircraft. Also, 35-millimeter slides were taken sequentially of ignition and fire buildup, smoke characteristics, and all test operations.

3.5.2. PILE FIRE

Two 16-millimeter movie cameras, mounted to obtain pictures at right angles to each other, photographed the pile fires. The cameras were operated continuously for short periods upon two-way radio command. Still cameras took 35-millimeter slides of fire and smoke behavior and test operations.

3.6. Meteorological Observations

Instrumented towers, located on the southeast and the north-central portions of the broadcast area, monitored meteorological conditions during the broadcast fire. The north-central tower carried an anemometer and wind vane, mounted at 13.7 meters to indicate the upwind conditions, but it was not functional during the fire. The southeast tower was 22.9 meters tall. Psychrometers and anemometers, mounted at 1.5, 4.6, 9.1, 13.7, 18.3, and 22.9 meters above the ground, monitored downwind conditions. A wind vane was

mounted on top of the tower. The signals from these sensors were recorded at 1-minute intervals on an automatic data-logging system. Due to the slope of the fire site, the base of the southeast tower was 3 meters below the fire level.

General meteorological conditions were also monitored at the ignition site (4.1.1).

Because of the failure of the upwind tower, upwind and downwind comparisons are not available.

4. RESULTS AND DISCUSSION

4.1. Broadcast Burn

4.1.1. FIRING TECHNIQUES

Ignition time was at 1338, June 25, 1968. Weather measured at the ignition station is shown in table 4. Within 15 minutes, a strong central draft formed and all ground level smoke flowed into it (4.1.4). The strong ground indraft was strengthened on the north and west sides by the NNW. prevailing wind. The smoke plume pierced a fairly pronounced inversion (detected by research aircraft) extending from 640 to 914 meters over the fire. The smoke plume rose to approximately 1,370 meters and sheared to the SSE. where it encountered the strong upper-level inversion base and drifted well away from the fire area.

By 1-1/2 hours after ignition, only disorganized small sources of smoke remained. In the absence of the strong convection column, this smoke drifted and diffused at low elevations. By 2-1/3 hours after ignition, little smoke was visible over the entire unit.

Fire control was not a problem. Although the fire was extremely turbulent, no spot fires occurred in the adjoining uncut stand, primarily because of the strong central convection column with the accompanying strong indraft at the edges of the burn: Firebrands were transported upward in the convection column where burnout ultimately occurred.

The thickened or gelled napalm used as the fuel booster on the clearcut burn has the trade name "Burnol." The manufacturers could not supply the chemical composition of this specific product; however, analysis made in Fontana, Calif., and at

Table 4.—*Weather measurements*[1] *at ignition station, broadcast burn, Pack Forest, June 25, 1968*

Time	Cloud cover	Temperature		Relative humidity	Wind	
		Wet	Dry		Direction	Velocity
		Degrees C.	*Degrees C.*	*Percent*		*Meters/second*
1050	0.1	19.4	25.8	56	NNW.	0.4-4.0
1210	.1	20.0	27.8	48	NNW.	.4-2.6
1315	.1	21.4	30.0	46	NNW.	1.7-5.2[2]
1430	.1	21.6	30.0	46	NNW.	1.7-4.3

[1] June 23 and 24 were sunny and warm. Seattle-Tacoma Airport reported 27° C. the afternoon of June 24, 1968.

[2] Gusts to 6.1.

the University of Washington as part of this study is shown in the following tabulation:

Compound	Percent	
Chevron gasoline (low octane)	94	100
Activating compounds	6	
Silica aerogell (devolatilized)	5	100
Aluminized soap[1]	95	
Organic acids from cocoanut oil (extracted copra oil) tri myristin, tri laurin, tri palmitin, tri stearic	50	100
Naphthalic acid	25	
Oleic acid	25	

[1] Traces of glycerides detected.

Calculated emissions from the fuel booster, total combustion assumed, are shown in table 5. When compared with the results of Darley's laboratory tests of cellulose fuel (section 4.3.2), the fuel booster could account for 11 percent of total CO (wood fuel plus fuel booster) and 3 percent of total CO_2 emitted during the clearcut burn.[9] Each fuel booster package achieved burnout in 7 minutes, according to averages obtained from burning tests of 12 packages. Total fuel booster burnout thus occurred 19 minutes after ignition. Total fuel booster emission was during this period.

However, during stage 1 (first hour of burning), CO and CO_2 concentrations measured by the sampling net at the ground level were low (5 and 500 p.p.m., respectively).

Hydrocarbon gases during stage 1 appear to be saturated and would not contribute appreciably to photochemical smog. These measurements are of emission from both fuel booster and woody fuel. Since the greatest plume rise occurred during this period, most emissions were carried well away from the fire area and were subject to rapid dilution. Visibility reduction was greatest during

[9] Fuel booster calculations assume total combustion and an estimated C:CO:CO_2 ratio of 2:1:7 and are not adjusted for smoke and residue as are those from Darley et al. (1966).

Table 5.—*Gaseous and elemental emission from the fuel booster used on the broadcast burn, Pack Forest, June 25, 1968*

Component	C		H		O		CO		CO_2	
	Kilogram	*Percent*	*Kilogram*	*Percent*	*Kilogram*	*Percent*	*Kilogram*	*Percent*	*Kilogram*	*Percent*
Gasoline	197.0	84.0	37.0	16	–	–	–	–	–	–
Organic fatty acids	4.8	76.0	0.9	11	0.9	13	–	–	–	–
Oleic acids	2.7	77.0	.4	12	.4	12	–	–	–	–
Naphthalic acid	2.5	6.7	<.4	4	1.1	30	–	–	–	–
Subtotal[1]	10.1	–	<1.8	–	2.5	–	–	–	–	–
Total	208.0	–	>38.0	–	2.5	–	–	–	–	–
All carbon converted to CO	–	–	–	–	–	–	461.0	–	–	–
All carbon converted to CO_2	–	–	–	–	–	–	–	–	724	–
C, CO, CO_2 produced in a 2:1:7 ratio	29.5	20.0	–	–	–	–	45.8	10	508	70

[1] Total amounts of C, H, and O in the minor components amount to 6 percent of the total material in the fuel boosters.

the early stages of the fire, and the fuel booster was responsible for some portion of smoke volume and density.

Lowry (1967) has published a physical model which is useful for estimating requirements for rise of large smoke plumes from prescribed fires. He suggests that rates of energy release are too small on most slash fires to achieve good plume rise necessary for minimization of air pollution. His model gives a basis for estimating the rate at which fuel must be burned to achieve a given plume rise under stated atmospheric conditions. Lowry's model was used to evaluate rates-of-energy release on the broadcast burn. The following measurements and assumptions were used:

Atmospheric pressure	P	=1.0 atmosphere
Gradient wind	u	=2 m. sec.$^{-1}$
Plume rise	H	=1,000 m.
Radius of plume at height times radius of burn area	r(R)	=200 m.
Radius of plume times vertical windspeed	r^2W	=2.0 x 10^5 m.^{3} sec.$^{-1}$
Dimensionless buoyancy	B	=0.2
Rate of heat generation	L	=6.8 x 10^9 cal. sec.$^{-1}$

Thus, to achieve a plume rise of about 1,000 meters, approximately 6.8 x 10^9 calories per second (cal. sec.$^{-1}$) heat release would be required.

Based on fuel consumption values from table 6, the same heat-of-combustion figures used by Lowry, observations by fire scientists assigned to the experimental burn, and integration over 2 hours of primary combustion activity, the maximum rate of energy release on the experimental burn was approximately 12.8 x 10^9 cal. sec.$^{-1}$ (fig. 7). This average release rate was achieved approximately 7 minutes after ignition and was maintained, on the average, until approximately 20 minutes after ignition. The plume rose to about 1,370 meters in spite of the inversion and, based on theoretical calculations, would have risen to about 1,830 meters had the plume not encountered the upper-level inversion.

This plume rise would not have been achieved with conventional slash burning techniques; i.e., low-temperature ignition devices, slow firing, slow and discontinuous fire development, and long burnout times. Although it is impossible to prove quantitatively from the data obtained during this study, we doubt if the smoke plume could have risen higher than the base of the low-level inversion, 600 meters without the electrical ignition and fuel booster system.

Direct costs of burning the 7.45-hectare (18.44 acres) unit were $116 per hectare or $47 per acre. These costs included the fuel booster and electrical ignition:

Item	Cost
Fuel booster	$371.76
Ignition squibs	118.50
Spitter fuse	6.00
Aluminum wire	72.20
	$568.46
Man-hours:	
Wire layout, 6 man-days	
Booster package preparation, 2 man-days	
Standby crew, 20 man-days	$287.30
	$855.76

Table 6.—*Weight changes on 7.45-hectare broadcast burn, Pack Forest, June 25, 1968*

Material	Total weight change		Change per hectare	Change per acre
	Short ton	*Metric ton*	*Metric ton*	*Short ton*
Duff	- 82.5	- 84	-11.3	- 4.47
0-1 cm. (includes brush)	- 63.7	- 64	- 8.6	- 3.45
1-10 cm.	- 19.8	- 20	- 2.7	- 1.07
> 10 cm. (1-cm. shell)	- 90.3	- 92	-12.3	- 4.90
Total	-256.3	-260	-34.9	-13.90

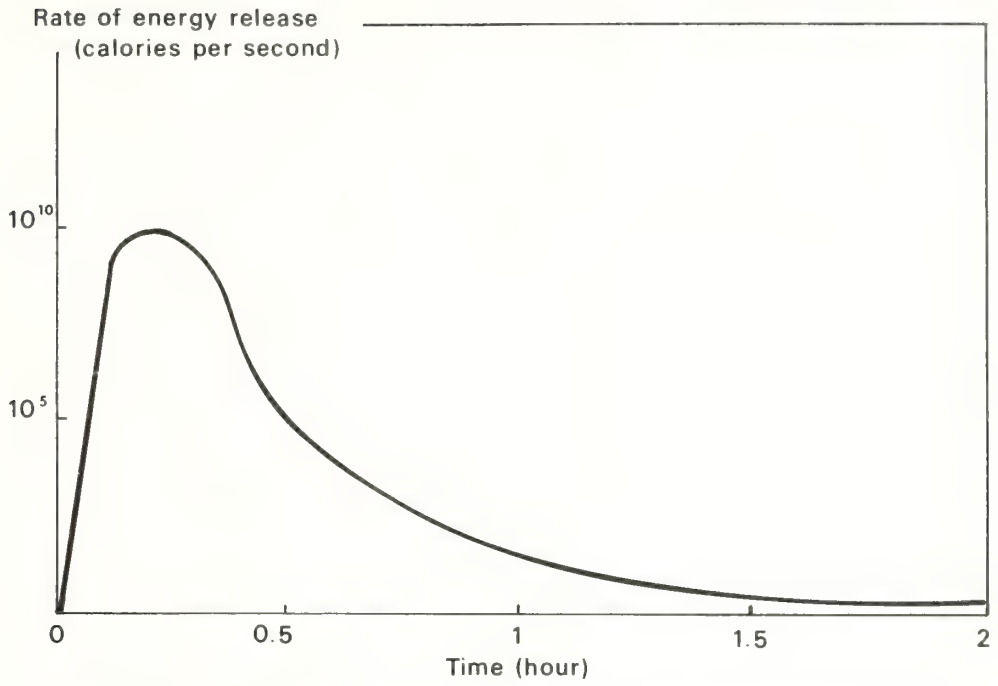


Figure 7. — Estimated rate of energy release for the broadcast fire on Pack Forest, June 25, 1968.

An adjoining 4.7-hectare unit was broadcast burned with conventional drip torches and diesel fuel. An attempt was made to obtain the same rapid rate of heat generation as on the 7.45-hectare unit. The cost of burning the smaller unit was $133 per hectare ($54 per acre). However, because the risk of wildfire was high, a 30-man standby fire control crew was used.

4.1.2. FUEL BURNED

The pre- and postfire inventories (3.2.1) were used to compute the total amount of fuel burned. The results are shown in table 6. The weight change for duff may be greater than shown. In postburn samples, no distinction was made in most cases between burned duff, unburned duff, and ashes. The weight of material greater than 10 centimeters in diameter increased after burning. This may have been due to the low sampling intensity or the bias introduced either by burial of this material by fine fuels before the fire or exposure of the material afterwards. However, only an outer shell of approximately 1 centimeter was charred on material 10 centimeters in diameter or larger. Because the amounts of material in this size class were approximately the same in both surveys, an estimate of the material which actually burned was made by computation of the volume per plot of this 1-centimeter shell and use of this figure in table 6.

Mineral soil exposed prior to the burn was estimated to be 10 percent; after the burn, 18 percent. This difference may not be statistically significant since only half of the plots were remeasured after the burn. The average duff depth before and after the fire changed from 5.53 to 2.71 centimeters. Some of the material represented as duff in the postfire remeasurement consisted only of ashes and some was partially burned. No measurements were made to determine relative proportions of ashes, burned duff, and unburned duff. However, reports by cooperating fuels scientists indicated total reduction in duff load on the area was light when the intensity of the fire was considered.[10]

[10] Fahnestock, G., and Morris, W. Unpublished report on file, Pacific Northwest Forest and Range Experiment Station, USDA Forest Service, Portland, Oregon. June 30, 1968.

4.1.3. FUEL MOISTURE

Moisture content for each stratum of the slash material was averaged for all plots. The results are shown in table 7.

4.1.4. PHOTOGRAPHY

On the basis of time-lapse photography, the June 25 fire was broken down into three stages, each with characteristic fire and plume behavior. The first stage was characterized by fire buildup, a hot fire, and convergence and eddy mixing in the resulting convection column. This stage lasted until 1410 (section 4.1.5) and was roughly equivalent to the period I gas samples, section 4.1.6.2.

Stage II, corresponding to period II gas samples (4.1.6.2), was characterized by a general dying down of the fire, a tendency for the convection column to bend over at the ground, but with abundant fire remaining in the area. The stage II fire gradually diminished until by 1510 only scattered hotspots, i.e., campfire-size blazes, remained in the area. This was termed stage III, although it had very indefinite beginnings. Most period III gas samples were taken after the fire had reached this stage. So little fire remained in the area that most experiments other than gas sampling were terminated.

4.1.5. METEOROLOGICAL CONDITIONS

General meteorological conditions at the ignition site were given in section 4.1.1. Meteorological conditions at the southeast corner of the broadcast burn are shown in figures 8 and 9. The prevailing wind was from the northwest at about 3 meters per second (m. sec.$^{-1}$). However, during stage I, the buildup period, air flowed into the fire from all directions. This is illustrated in figure 8, between 1340 and 1410. The shaded area of wind directions indicates the period of airflow into the fire. During this period, the windspeed decreased as the air started to converge. Windspeed increased as convergence reached a maximum at 1510, then decreased as the fire started to lose energy. During stage II of the fire, the wind direction switched around to the northwest again and the velocity increased to the original level.

Air temperature substantiates the above statements (fig. 9). The inexact correlation between wind direction and low air temperatures is due to the difference in time response of the wind vane (instantaneous) and the temperatures (about 2 minutes). During the buildup, the temperature dropped as fresh air moved into the fire (fig. 9, 1340 to 1410). Air temperature increased again as the wind direction changed to the northwest,

Table 7.—*Moisture content (expressed as percent ovendry weight) of fuel on sample plots prior to broadcast burn, Pack Forest, June 25, 1968*

Material	Moisture content	Standard deviation	Range
		Percent	
Brush	190	136	7-622
Duff, ground	48	22	18-120
Duff, midtransect	28	30	5-141
Duff, top	19	15	4- 34
0-1 cm., ground	21	31	2-165
0-1 cm., midtransect	25	48	7-282
0-1 cm., top	17	12	2- 78
1-10 cm., ground	22	7	11- 49
1-10 cm., midtransect	19	8	2- 45
1-10 cm., top	23	7	10- 39

causing the heated air from the fire to reach the temperature sensors. The fire energy system obviously dominated the mesoscale weather at the burning site during the 1340-1410 period.

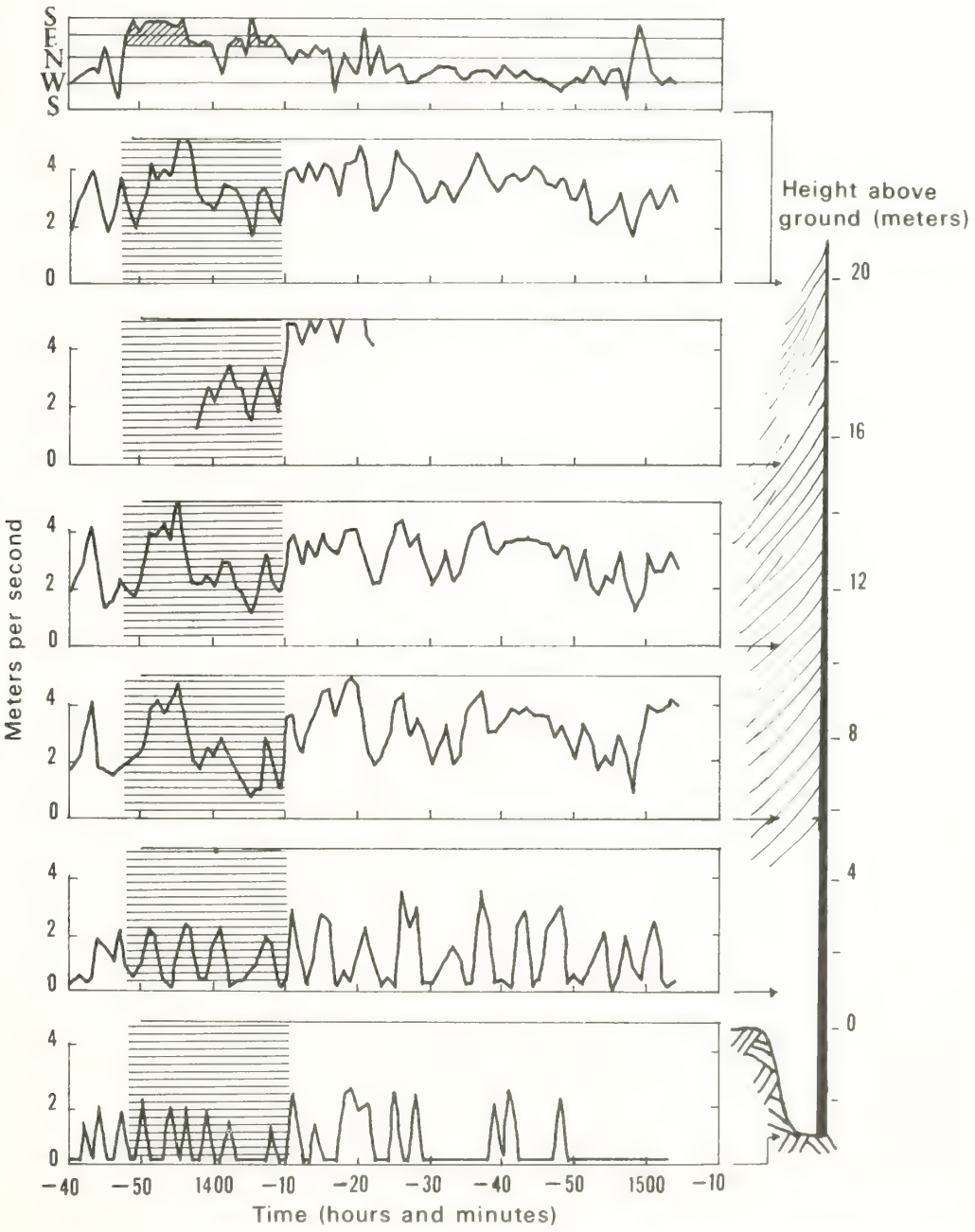


Figure 8. – Wind direction and speed monitored on the southeast corner of the broadcast fire on Pack Forest, June 25, 1968.

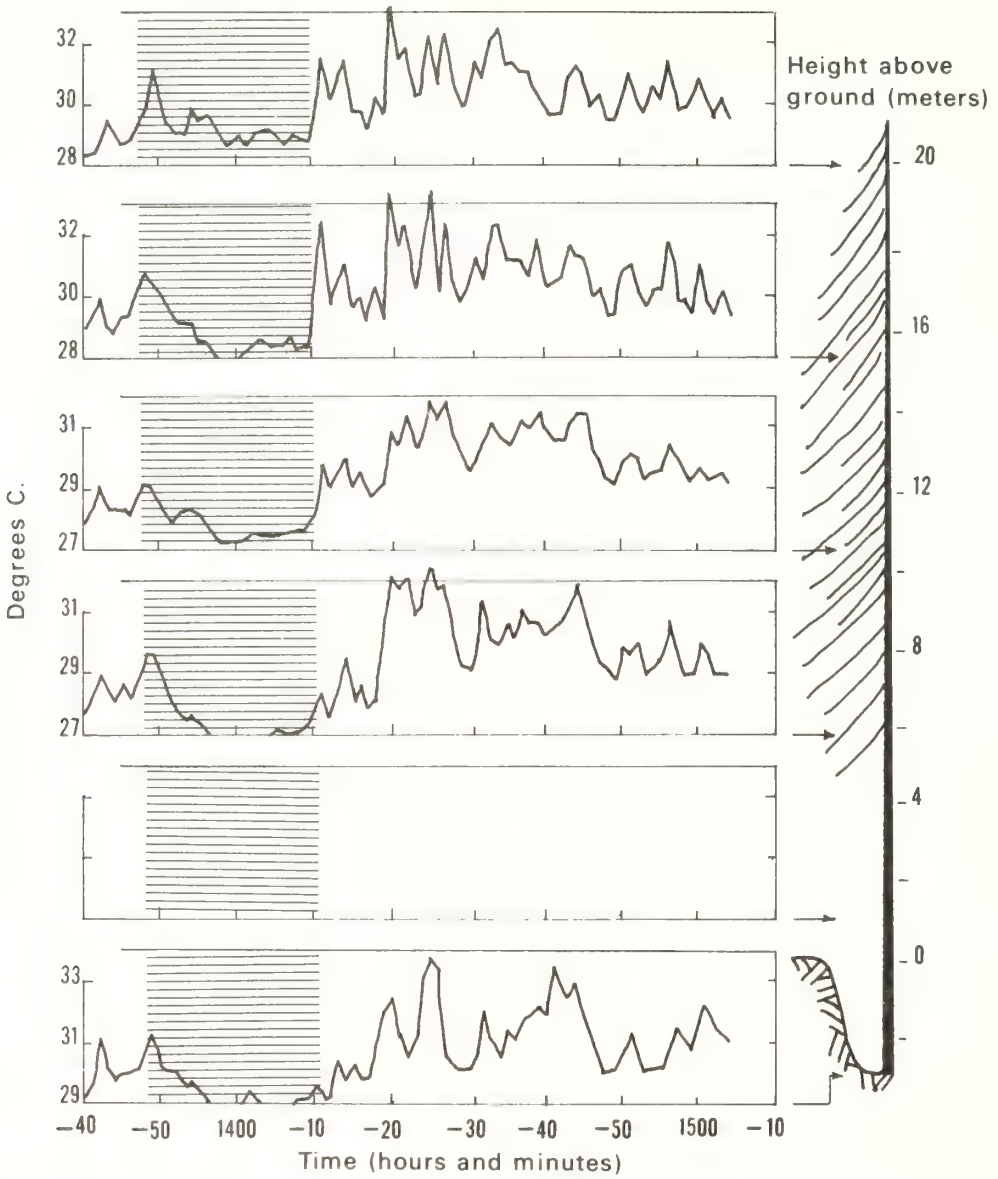


Figure 9.—Air temperatures monitored on the southeast corner of the broadcast fire on Pack Forest, June 25, 1968.

4.1.6. EMISSION ANALYSIS

4.1.6.1. Suspended particulate matter. — Gas chromatographic analysis of the benzene extracts from the high-volume filter mats showed up to 50 distinguishable peaks. Mass spectral data, obtained simultaneously, indicated the presence of alkanes, alkenes, alcohols, ketones, and essential oils.

The particulate loading and extractable percentage before and during the burning is shown in table 8. The background particulate loading was high for a rural area and probably due to slash burning on the previous day. The particulate loading increased the morning of June 25 prior to ignition. This may be due to increased vehicular traffic in the area by study personnel. At least two

Table 8.—*Particulate loading and extractable percent obtained with high volume samples before and during the broadcast slash burn at Pack Forest, June 24-25, 1968*

Material number	Collection period		Particulates	Extractable percentage
			$\mu g.m.^{-3}$	
88	1000	June 24	64	6.4
	0923	June 25		
73	0900	June 25	160	22.0
	1334			
87	1334	June 25	1,150	30.8
	1430			
86	1431	June 25	1,510	34.2
	1629			
85	1630	June 25	950	25.4
	1827			

other slash fires in the vicinity were noted by personnel in the aircraft prior to ignition. Particulate matter from these fires may also have increased the prefire background as well as the extractable percentage.

The problem of visibility reduction in the Northwest can be visualized when average particulate loadings above major U.S. cities for 1961 are compared:[11]

City	Particulates ($\mu g.\ m^{-3}$)
Chicago	190
New York City	173
Philadelphia	173
Milwaukee	146
Baltimore	142
St. Louis	141
Pittsburgh	137
Cleveland	136
Washington	128
Detroit	118
Dallas	92
Seattle	87
Atlanta	84
Miami	54

[11] From U.S. Department of Health, Education, and Welfare (1966), table 2.3.

The Northwest atmosphere is typified by good visibility and relatively low particulate loads. Thus, any increase in particulate loading and subsequent decrease in visibility, especially in the direction of the surrounding mountains, is readily noticed by both the inhabitants and news media in the area. This problem is not as severe in other areas, i.e., New York, Chicago, etc., where visibility is typically much lower.

Plume characteristics are shown by aerial soundings in figure 10. Location of each sounding is shown in figure 1. The first, 1215, was made during the flight from Seattle to the experimental site. The local industrial pollutants appear to be concentrated in the low-level inversion between 300 and 600 meters. These data are summarized in table 9. Average particulate loading prior to ignition was about the same over both the fire site and the Seattle industrial area. However, the peak loading was much greater over the industrial area. Significantly, the 1722 and 1742 particulate loadings near and over Puyallup (primarily residential and light industry) were not increased above that observed over the Seattle industrial area before the fire, even though the plumes of at least three slash fires had drifted over the area. The particulate sample periods from 1334 to 1827 in table 8 generally represent the three fire stages. Between 1334 and 1431 (stage I), particulate loading increased but the strong central convection column with horizontal inrushing winds carried most

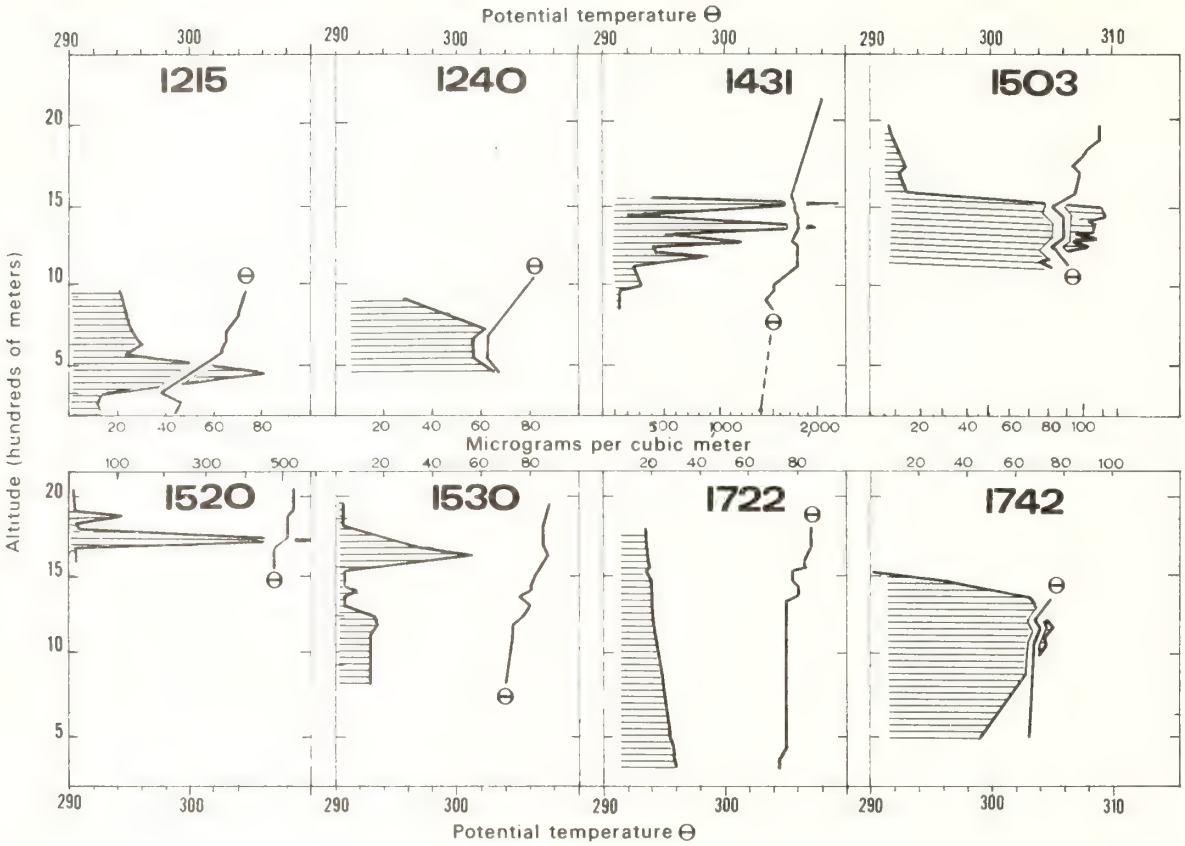


Figure 10. – Mass of suspended particulates and potential temperature observed during vertical soundings of the plume from the broadcast fire, Pack Forest, June 25, 1968.

Table 9.–*Summary of aerial particulate soundings associated with the experimental fire, June 25, 1968*[1]

Time	Location	Altitude	Particulate			Average meteorological range
			Average	Peak	Background	
		Meters		*μg.m.*$^{-3}$		*Kilometers*
1215	58 km. NE.	152- 488	48	129	30	24.0
1240	Over burn	579- 823	60	66	21	20.0
1431	3.9 km. N. 72° E.	914-1,584	690	1,980	18	1.6
1503	17.1 km. N. 60° E.	1,310-1,524	186	216	18	6.2
1530	31.9 km. N. 39° E.	1,524-1,768	123	181	12	9.5
1722	28.1 km. N. 18° E.	244-1,555	58	84	3	20.2
1742	40.2 km. N. 4° E.	457-1,494	27	75	3	43.3

[1] Refer to figure 1 for location.

of the particulates aloft. Loading was greatest during the diedown stage II (1431 to 1629) when prevailing wind carried the smoke over the sampling site. The extractable percentage also increased. Total particulates decreased in the last period (stage III) and the extractable percentage reduced to the prefire level. The 1240 sounding over the experimental site shows a pronounced inversion between 518 and 640 meters and, when combined with the 1431 sounding, illustrates the atmospheric stability.

The convection column broke through the lower inversion, reaching 1524 meters before drifting horizontally (1431). As the plume drifted away from the fire, it rose slightly from 1,524 meters to 1,737 meters and appeared to follow the 308° to 309° K. potential temperature surface. The 1742 sounding shows the particulate loading associated with two other lower energy slash fires.

The particulate loading of the plume diluted downwind. This can be shown as the meteorological range. The meteorological range is the visual range which would be observed if the air were perfectly homogeneous and is related to particulate loading by

$$\text{Meteorological range (m.)} = \frac{11.7 \times 10^5}{\mu g.\ m.^{-3}}$$

Meteorological range increased from 0.5 kilometer in the plume at the fire to 4 kilometers at a distance of 32 kilometers downwind. In contrast, the meteorological range varied from 25 kilometers to 100 kilometers over the Seattle industrial area prior to the burn. The meteorological range of the background air in the 1431 through 1530 soundings was about 100 kilometers.

The particulate loading appeared to be diluted by about twofold to tenfold from the ground site to the horizontal plume at the fire. When this dilution factor is combined with the CO_2 dilution factor from the fire to the ground sampling net of 40 to 60, the result would indicate a total dilution of 80 to 600 from the fire to the top of the convection column.

4.1.6.2. Carbon monoxide and carbon dioxide. — The results of carbon monoxide and carbon dioxide analysis are shown in appendix 9.1.1 for the broadcast fire and appendix 9.1.2 for the pile fire. The data for the broadcast fire are summarized in table 10.

The CO and CO_2 concentrations decreased rapidly from the fire through the sample net. Dilution of hydrocarbons and particulate matter was probably comparable. The distributions of CO and CO_2 downwind from the broadcast fire are shown as isopleths in figures 11, 12, and 13.

The concentration from the flames (table 10) to the first line of the sample net changed by a factor of about 520 to 980 for CO, and from 40 to 60 for CO_2. This may indicate that CO underwent further oxidation from the fire to the sample net.

The particulate loading changed by a factor of about 2 from the high-volume filter (period I) to the plume (1431 nephelometer sounding). The average concentration of all hydrocarbon gases changed by about the same factor as the particulate loading from station 9-1, near the high-volume filter during period I, to the airborne grab sample taken just prior to the 1431 sounding. These changes are summarized as follows:

Concentration ratios for various smoke components from broadcast fire, Pack Forest, June 25, 1968

Component	Flame:sample net	Sample net:aircraft
CO	520 – 980	83
CO_2	40 – 60	([1])
Particulates	([1])	1.67
Hydrocarbons (all gases)	([1])	2.7

[1] Unknown.

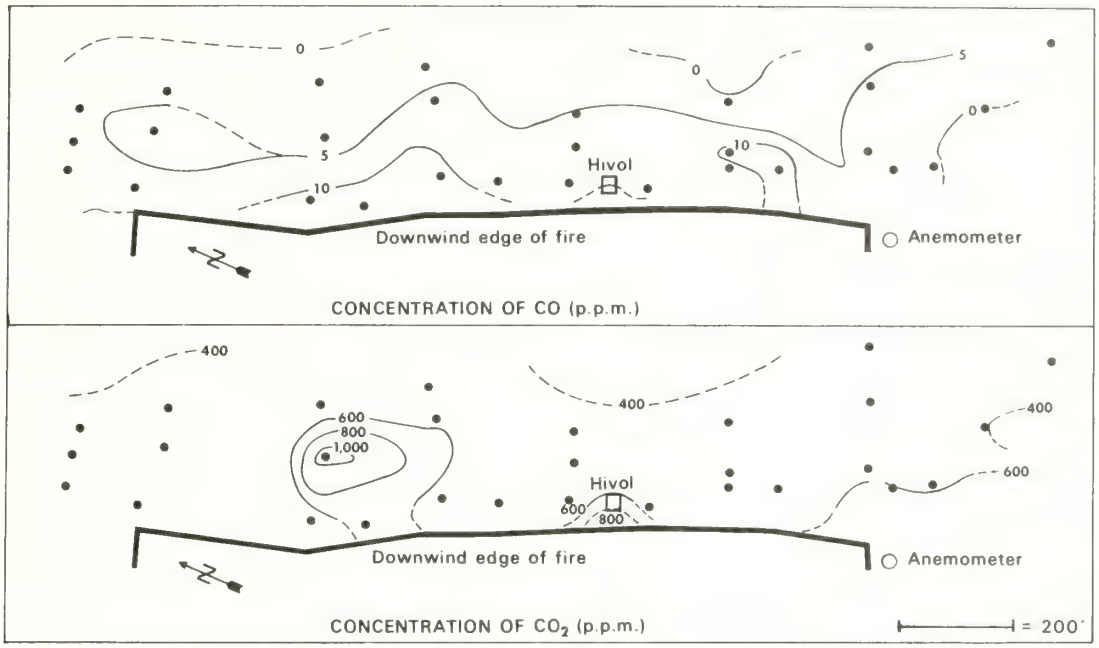
No CO was detected in the 1431 grab sample from the aircraft. The CO_2 concentration in the same sample was 330 p.p.m. The oxidation of CO may have reduced its concentration from an expected 4 p.p.m. to below the detection limit of 1 p.p.m. If both the sampling and analysis are reliable and 0.1 p.p.m. is the maximum undetectable concentration of CO, the minimum change in CO concentration from the sample net to the aircraft would be 83. This change in CO concentration is assumed to be due to oxidation. If the CO_2 concentration changed by the same factor as the particulate and hydrocarbons, the measured CO_2 concentration at the aircraft should have been 60 p.p.m. above ambient CO_2 concentrations. However, no ambient measurements were made.

This sample was taken from an aircraft flying within the plume. If it had been a true point sample, then there is a reasonable chance that the sample was taken from a pocket of unmixed ambient air within the plume. However, the tank in which the sample was taken requires about 10 seconds to fill. If the plane was moving at 40 $m.sec.^{-1}$ (90 m.p.h.), then the sample was taken

Table 10.—*Concentration of major plume components from broadcast fire, Pack Forest, June 25, 1968*

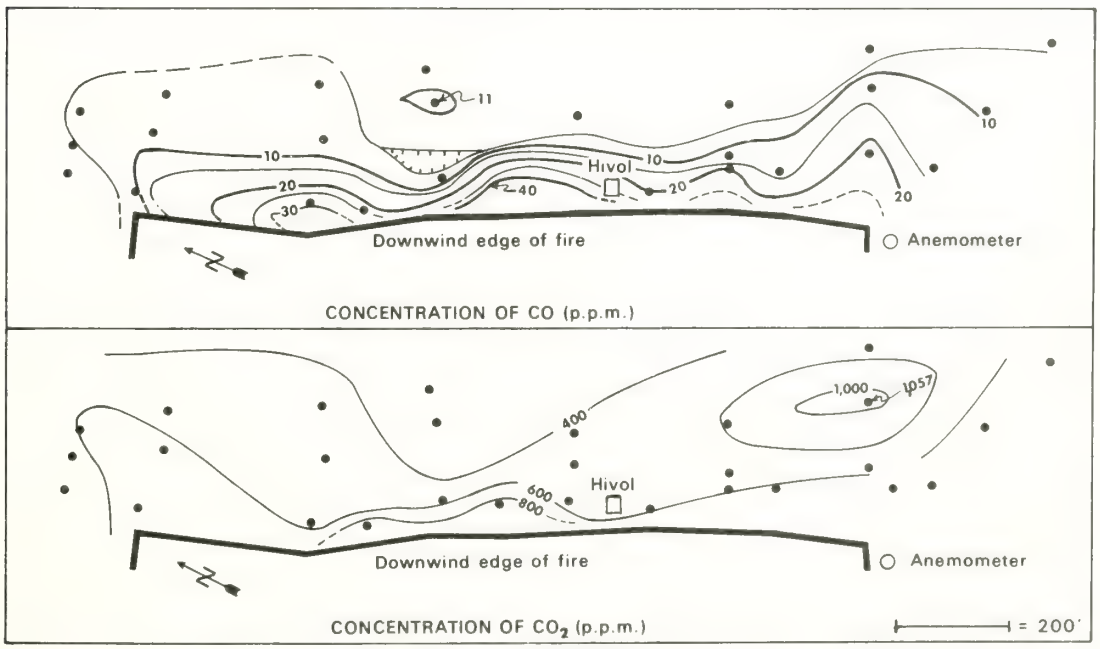
Sample	Flames			Line 1		Line 2		Line 3		Average all lines		1431 sounding (4 kilometers downwind 1,800 meters)
	850° C.	500° C.	500° C.									
	------Parts per million-----			Average parts per million	Sd.[1]	Average parts per million	Sd.[1]	Average parts per million	Sd.[1]	Average parts per million	Sd.[1]	Parts per million
CO:	917	4,315	8,104									0
Period I				8.1	3.2	5.2	3.8	5.2	2.6	6.5	3.4	
Period II				18.7	10.3	10.0	3.3	6.8	1.1	13.8	9.7	
Period III				6.5	2.8	7.6	.6	5.6	3.8	6.6	2.7	–
CO_2:	31,000	22,000	40,000									330
Period I				561	97	620	251	480	37	555	149	–
Period II				626	154	665	232	575	127	625	164	–
Period III				530	118	519	93	596	188	543	129	–
$CO/(CO_2{}^{-330})$ (average):	0.029	0.194	0.203									
Period I				0.039	–	0.024		0.035	–	0.034	–	–
Period II				.072	–	.036	–	.033	–	.054	–	–
Period III				.045	–	.048	–	.066	–	.051	–	–
Particulate:	–	–	–	$\mu g.m.^{-3}$								$\mu g.m.^{-3}$
Period I				1,150	–	–	–	–	–	–	–	690
Period II				1,510	–	–	–	–	–	–	–	–
Period III				950	–	–	–	–	–	–	–	–
Methane:	–	–	–									
Period I				–	–	–	–	–	–	–	–	–
Period II				2	–	–	–	10	–	–	–	2
Period III				2	–	–	–	–	–	–	–	–
Methanol (period II)	–	–	–	1.92	–	–	–	–	–	–	–	0.45
Benzene (period II)	–	–	–	.03	–	–	–	–	–	–	–	.00
Toluene (period II)	–	–	–	.40	–	–	–	–	–	–	–	.04

[1] Standard deviation.



Period I 1300–1430

Figure 11. – Horizontal distribution of CO and CO_2 during period I of the broadcast fire, Pack Forest, June 25, 1968. (Shown as isopleths.) Data indicate location of water displacement air samplers.



Period II 1430–1630

Figure 12. – Horizontal distribution of CO and CO_2 during period II of the broadcast fire, Pack Forest, June 25, 1968. (Shown as isopleths.)

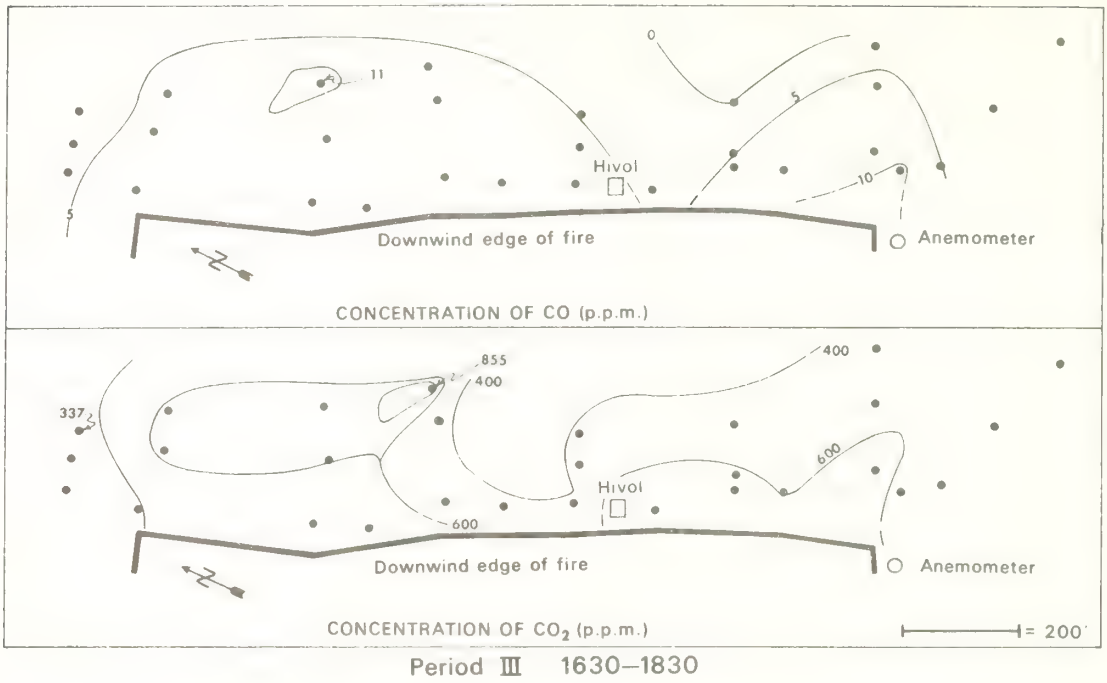


Figure 13.—Horizontal distribution of CO and CO_2 during period III of the broadcast fire, Pack Forest, June 25, 1968. (Shown as isopleths.)

over a 400-meter segment of the plume. Integration of the sample over this distance should provide detectable quantities of both CO and CO_2 if present in greater than ambient concentrations.

The change in the ratio of CO to CO_2 during the fire is apparent in figure 14. CO versus CO_2 concentration at each point in the sample net is plotted for each period. The slopes (m) of the $CO:CO_2$ ratios obtained from the 500° and 850° flame gases are indicated by the dashed lines. The smoke in period I apparently originated from flames between 500° and 850° C. However, in period II, several of the samples taken along line 1 fall very close to the slope of the cooler flame.

Ventilation was available for fuels in the interior of the burn because of turbulence associated with the stage I convection column. The gradient wind which predominated in stage II provided less interior ventilation. The better interior ventilation during period I plus the rapid consumption of flash fuels (0-1 cm.) created higher temperatures and more complete combustion during stage I. During stage III, almost all of the finer fuels had been consumed. With the exception of smoldering duff, the fire was confined to small, well-ventilated, and compact piles of heavier fuels in which flame temperatures were again higher, and combustion more complete than during stage II.

The $CO:CO_2$ ratio from the 850° flame gases approximately equals the $CO:CO_2$ ratio from laboratory combustion of Douglas-fir slash (4.3.2). This indicates that both the temperatures and the degree of combustion were approximately the same in the field during stage I and under laboratory conditions. The strong convection column of the stage I fire created return eddies which provided a strong backwind around the perimeter of the fire. The plume components during this stage therefore were transported through the sample net from line 3 (most distant) to line 1 and back to the fire. When the convection column could no longer penetrate the inversion during stage II, the gradient wind carried the plume directly across the downwind fireline and through the sample net from line 1 to line 3.

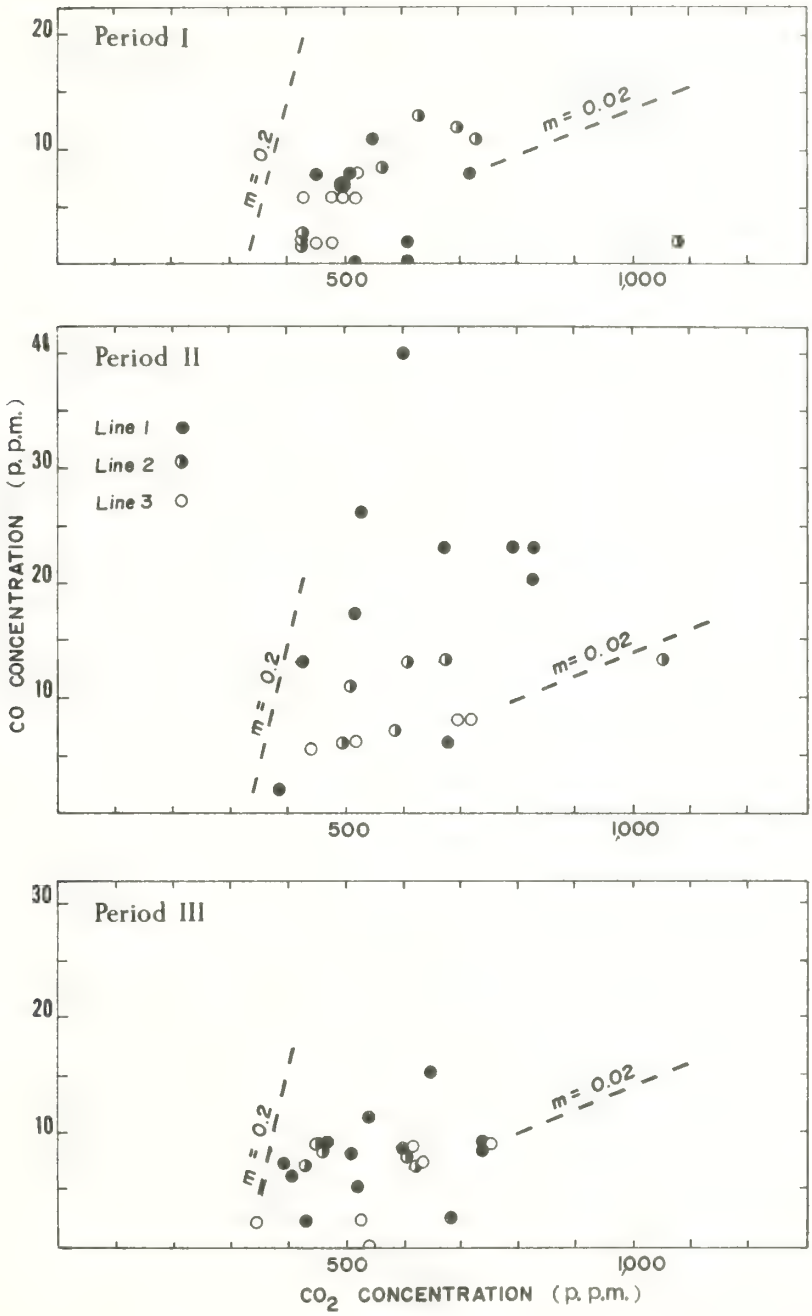


Figure 14. — Concentration of CO vs. CO_2, by period, for smoke collected in sample net from broadcast fire, Pack Forest, June 25, 1968. The slopes of the CO-CO_2 ratios are represented by m.

The stage II plume underwent rapid and apparently nonuniform dilution from the fire to the first line of samplers in the sample net. From line 2 through the remainder of the sample net, CO, CO_2, and probably the other plume components as well underwent uniform and less rapid dilution. Five points in figure 14 which represent samplers on line 1 lie on a line almost identical with the slope of the CO:CO_2 ratio from the 500° flame gases. The slope of the regression of all points along line 1 is much less – 0.025. The slope of the regressions for all points on lines 2 and 3 are 0.009 and 0.008, respectively – identical for practical purposes. The CO-axis intercepts of the two regressions are 3.85 and 2.01 for lines 2 and 3, respectively. This downward shift and constant slope of the regression would be expected for two gases diluting equally.

Samples PB-1, PB-3, and G-11 were taken as close to the fire as a man could walk without a fire suit.

Carbon monoxide readings taken directly in the smoke cloud at ground level with Monoxor chemical detector tubes were 40 p.p.m. early in period II. Thirty minutes later the readings were down to 20 p.p.m.

4.1.6.3. Hydrocarbon gases. – Infrared spectrophotometer analysis of gas samples from the fire area and from the air collected in the plume at 1,370 meters is shown in table 11. Description of the sample location is given above. Samples G-4 and G-2 were taken with the airplane and show only background levels of methane. Threshold limit values[1 2] of pollutants established for 1968 (Anonymous 1968) are listed as follows:

Pollutant	Maximum 8-hour concentration (P.p.m.)
CO	50
CO_2	5,000
MeOH	200
EtOH	1,000
Acetone	1,000
Benzene	25
Toluene	200
Xylene	100

Values of CO and CO_2 in the fire gas samples with the exception of samples taken in the fire were much lower than the limits.

Detailed analyses of gas samples by a combined gas chromatograph-mass spectrometer technique are shown in table 12. In general, the gas concentrations of all of the components are low.

The most significant components appear to be the low molecular weight hydrocarbons and alcohols including ethylene, ethane, propene, propane, methanol, and ethanol. Acetone and the aromatic compounds benzene and toluene also appear in most of the samples. Several unsaturated com-

[1 2] Threshold limit values are airborne concentrations of toxic materials to which workmen can be exposed 8 hours a day, 40 hours a week, without adverse effects.

Table 11.—*Infrared spectrophotometer analyses of smoke samples, broadcast fire at Pack Forest, June 25, 1968*

Component	PB-1[1]	PB-3[2]	G-11[3]	G-4[4]	G-2[4]
			Parts per million		
Carbon dioxide	490	820	580	330	320
Carbon monoxide	24	58	40	0	0
Methane	4	10	5	2	2
Ethylene	1	1	1	0	0

[1] PB-1, period II (see fig. 4 for location).
[2] PB-3, period II (see fig. 4 for location).
[3] G-11, period II (see fig. 4 for location).
[4] G-2, G-4 collected from smoke plume with airplane.

Table 12.—*Combined gas chromatograph-mass spectrometer analysis of smoke samples from broadcast burn, Pack Forest, June 25, 1968*

Component	Activated charcoal	Sample location						
		A-3[1]	I-1[2]	E-1[3]	PB-1[4]	G-11[4]	G-4[5]	G-2[5]
	Parts per million							
Ethylene	0.03	0.07	0.05	0.01	0.99	1.05	0.04	0.09
Ethane	.01	.02	.02	0	.50	1.25	.02	.05
Carbonyl sulfide	0	1.00	.50	.50	0	0	0	0
Propene	.13	.02	.01	0	.34	.70	.60	.01
Propane	.09	.01	.01	0	.21	.60	.01	.02
Methanol	0	3.07	1.92	1.60	1.03	2.86	.45	.34
Freon 12	.01	0	.90	0	0	0	0	0
Acetaldehyde	0	.04	.02	.03	0	0	0	0
Isobutane	.01	0	.21	0	0	0	0	0
Butene-1	.16	.05	0	.08	0	0	0	0
Ethanol	0	.18	.26	.06	.14	.10	.06	.15
Furan	.04	0	0	0	.12	.45	0	0
Acetone	0	.01	.05	.01	.24	.37	.02	.23
Dichloromethane	.01	.65	.48	.11	0	0	0	0
Dichlorethylene	.01	0	0	0	0	0	0	0
N-pentane	.01	0	.04	.01	0	0	0	0
Pentene-2	0	.02	.02	0	0	0	0	0
Methylfuran-2	0	0	0	0	.03	.17	0	0
Ethyl acetate	0	0	0	0	.39	.80	.03	.12
Benzene	.07	.04	.03	.03	.09	1.79	0	.01
2,4-dimethyl 2-pentene	0	.02	.02	0	0	0	0	0
N-heptane	0	0	0	0	.01	.72	.01	.01
1,1,2 trichloroethane	0	3.42	.44	.21	0	0	0	0
Toluene	.01	.07	.40	.03	.11	.09	.04	.02
Xylene	0	.04	.07	0	0	0	0	0

[1]Sample A-3 taken during period III.

[2]Sample I-1 taken during period II.

[3]Sample E-1 taken during period III.

[4]See figure 4 for location of PB-1 and G-11.

[5]See figure 1 for location of G-4 and G-2.

pounds in addition to ethylene and propene were identified, but the quantities found were relatively low.

The activated charcoal results represent a much larger sample of air than the bag or tank samples. Because of this, many compounds were detected which could not be seen in the small samples. Only compounds with concentrations of 0.01 p.p.m. or greater have been included in table 12 because of the uncertainties in identification at lower levels and also the increased likelihood of seeing background contaminants instead of compounds from the burn.

A number of compounds were detected that are known or suspected to have been introduced accidentally. Freon 12, for example, was found in samples near the nephelometer which employs this gas in its operation. Carbonyl sulfide was found only in bags sealed with black rubber stoppers. 1,1,2 trichloroethane was found only in those plastic bag samples which were not analyzed soon after collection. In retrospect, a number of anomalies in the data might be ascribed to gradual permeation into and out of the plastic bags. Permeation problems should not occur in the stainless steel tanks or in the activated charcoal sample which was stored in a sealed glass container until analysis. In future studies of this kind, special precautions should be taken to avoid potential changes in the samples while in storage.

4.2. Pile Fire

4.2.1. CARBON MONOXIDE AND CARBON DIOXIDE

In contrast to the broadcast fires, the pattern of combustion and emission of CO and CO_2 was nearly constant in pile fire sampled on July 11. Flame temperatures were higher and combustion was more complete. The fire was hot enough to ignite adjacent stumps and duff. Smoke from these spot fires was drawn into the plume of the pile and interfered with plume gas measurements.

The results of the CO and CO_2 analysis of samples taken from the fire are plotted in figure 15. The CO:CO_2 ratio is relatively constant throughout the fire except where smoke from the spot fires obscured it. In addition to its relative constancy, the CO:CO_2 ratio for the pile fire was considerably lower than the average for the broadcast fire, as expected.

The ratios obtained from the pile are lower than from an 850° flame in the broadcast fire, lower than the average in the sample net for period I, and lower than that obtained from the laboratory burn. This suggests that laboratory analysis does not take place under any better conditions for complete combustion than those which can occur in the field. That piled slash burns hotter and cleaner than broadcast slash is no revelation. However, fuel arrangement in laboratory burning experiments might be adjusted to give results closely paralleling field conditions.

4.2.2. PHOTOGRAPHY

Motion picture film of the pile fires taken at azimuths 90° apart were used to study: (1) the three-dimensional trajectory of four balloons; (2) the two-dimensional velocities of flames and smoke; (3) the diameter of the flames at different altitudes; (4) the development of eddies and fire blobs.

The results of the three-dimensional trajectory of four balloons and several two-dimensional velocities of flames and smoke are summarized in figure 16. Although flame speed of 18 m.sec.$^{-1}$ and smoke speed of 15 m.sec.$^{-1}$ were observed, the greatest frequency of flame speed appeared to be 3 m.sec.$^{-1}$ and represented laminar flow. In contrast, the speeds between 11 and 18 m.sec.$^{-1}$ represented extremely turbulent motion with strong horizontal components and erratic changes.

The colored motion pictures were also used to determine relative flame temperatures. For future work three color steps should be calibrated. This would result in flame temperature and possibly air composition data. One series of determinations is shown in figure 17. Three distinct portions of a free flame are described:

1. The inner, dark-reddish (i.e., "cooler") portion, which corresponds to the darker inner portion of a candle flame. This region seems to receive large amounts of distilled fuel gases as well as solid and liquid particulates from the fuel bed below. Oxygen supply is insufficient, and the mixture is very "rich." If portions of this cooler stream accidentally escape directly into the air after flaming out, one can observe a substantial flow of smoke. This seems to be the more important source of gaseous, liquid, and solid air pollution.

2. The yellow portion of "intermediate" temperature has much better oxygen supply from

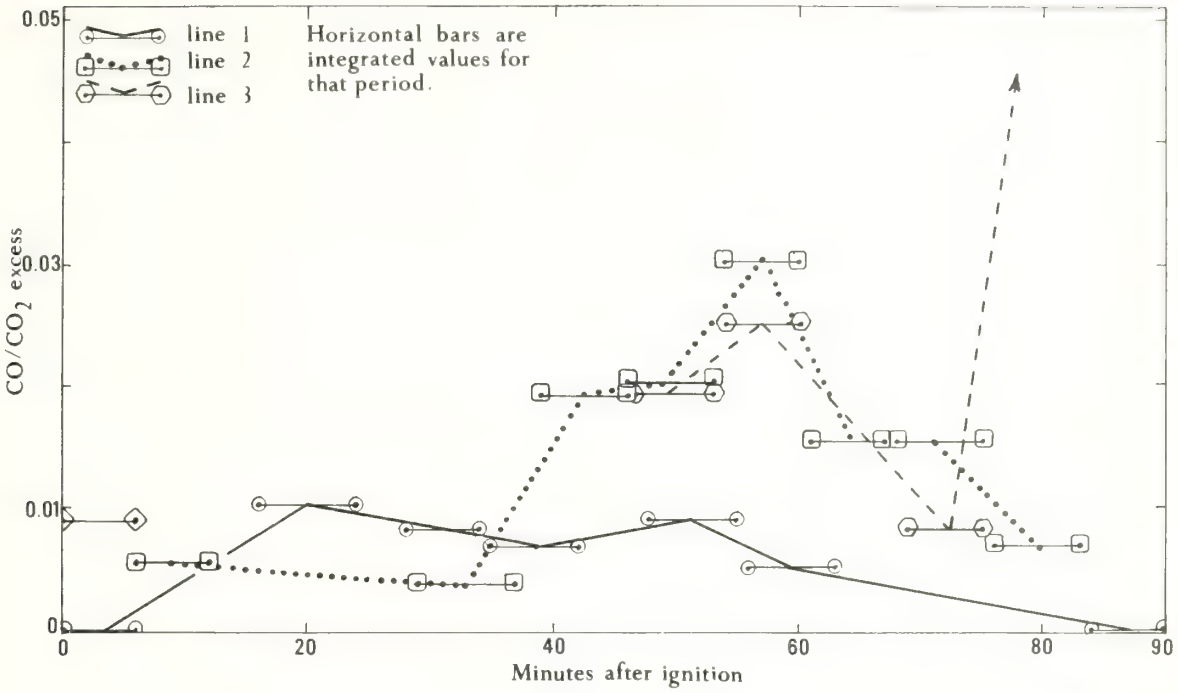
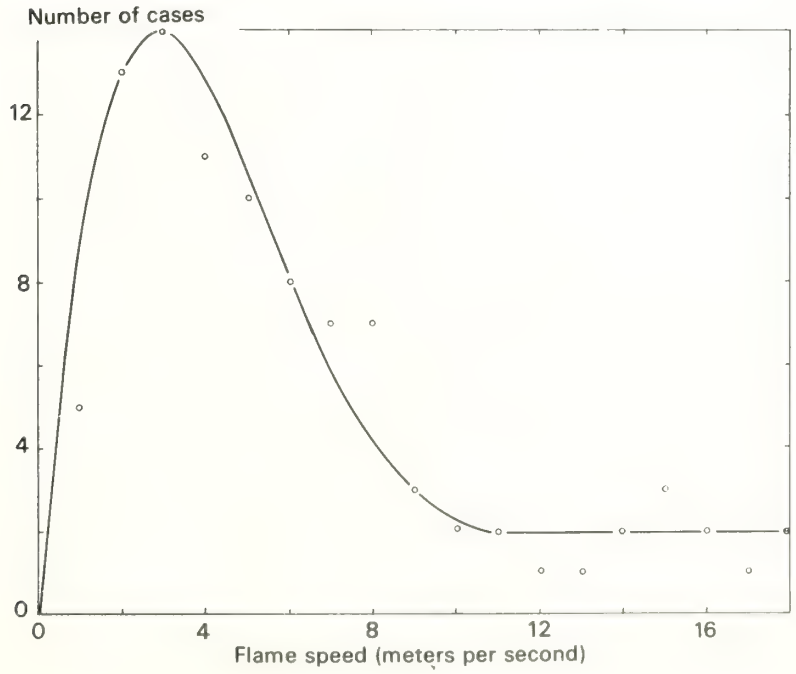


Figure 15. – Ratio of CO to CO_2 concentrations for smoke collected in water samples from pile fire, Pack Forest, July 11, 1968.

Figure 16. – Frequency of flame and smoke speeds observed from photography of pile fires.



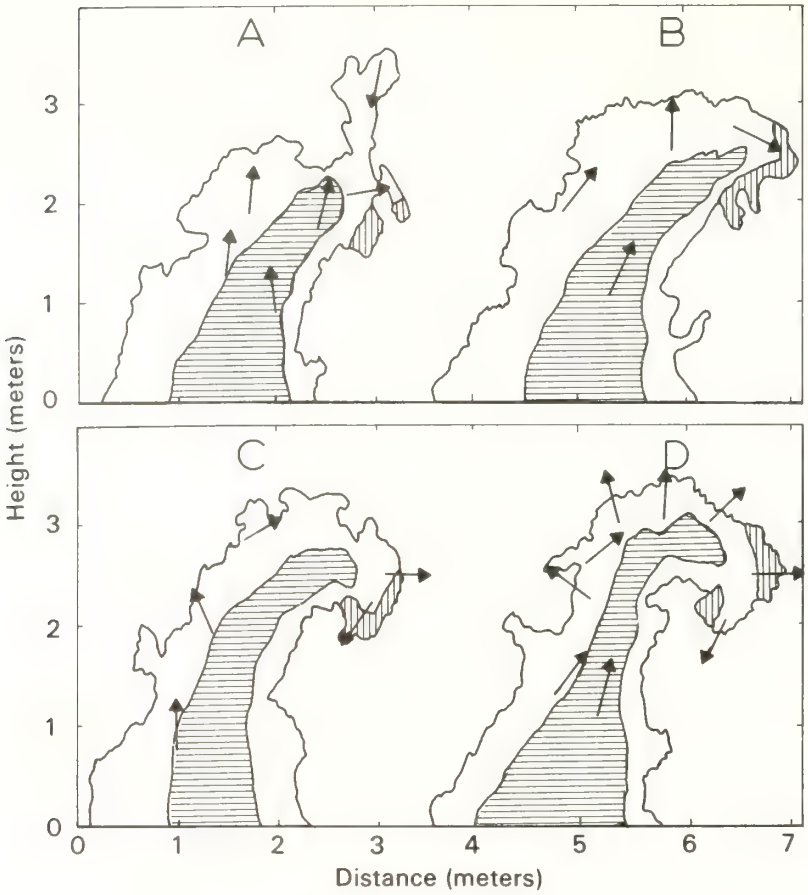


Figure 17. — Relative flame temperatures as determined from colored motion pictures of pile fires. Horizontal lines represent cooler portion, clear area represents intermediate temperatures, and vertical lines represent hottest temperatures.

sideways entrainment of fresh air. The mixture is less "rich" and the high radiation emission is due to large amounts of glowing particulates which are partially consumed in this part of the flame.

3. Once in a while small peripheral sections of bluish-white incandescence are seen. These hottest portions may very well reach a stoichiometric mixture and therefore temperatures may well exceed 1,000° K. In a candle flame, this portion is seen as a very thin blue mantle wrapped around the yellow flame. In this mantle the melting point of platinum, 2,000° K., is exceeded, as observations show. No smoke (solid or liquid light scattering particulates) issues from these hot portions. These white blobs do not contribute to air pollution.

4.2.3. MODELING OPEN FIRES

The three pile fires studied in this project were roughly cubical beds of packed wood. The resulting flame was slightly smaller in diameter and somewhat larger in height than the fuel bed. In these relative portions, they are quite different from a conflagration such as Hamburg (Germany) fire, resulting from bombing missions during World War II, where fire diameter far exceeded flame height which again far exceeded height of fuel bed; i.e., the average building. Former tests, conducted by G. Fahnestock in 1954 in Priest River, Idaho, and using flat fuel bed where no air could enter the fuel bed from below or from the sides, showed quite different behavior. In this case, the central

vertical flame diameter was about one-fifth of fuel-bed diameter.

These fires will be discussed with respect to four simple models: a chemical model, a rising airspeed model, a geometric model, and a pressure gradient model.

A simple chemical model of a flame may be the burning of 1 mole of $(CH_2O)n$ in 1 mole of O_2 into aliquot numbers of CO_2 and H_2O. Since measured CO_2 rarely exceeds 10 percent of the flame gas volume, a similar amount of combustion-created H_2O may be present. Burnable wood in general contains but a few percent of free water. The main mass of gas moving through a fire is therefore nitrogen. The total molar mass increase will barely exceed 10 percent. Since the volumes involved are strongly controlled by temperature and temperatures are not too well known, changes in masses moved as well as changes of average molecular weight may be neglected.

In a simple geometrical model, the flaming portion of a compact fire may be likened to a vertical cylinder of flame height (z_0) and radius (r_0). Into its periphery, an air volume of $\rho_0 \cdot u_0 \cdot 2\pi r_0 \cdot z_0$ (m.^{3}sec.$^{-1}$), density = ρ, will be moved, and a nearly equal volume $\rho_1 \cdot w_1 \cdot r_0^2\pi$ will leave at the top level of the flames (see chemical model). The coordinates used are as follows: x is the direction from an observer into the fire; v is the horizontal component perdendicular to x; z is the mean height; u, v, and w are vector flows in the x, y, and z directions. "Gradient" wind is the wind outside of the fire. Subscript 0 means near the fire border.

The speed of wind into the fire or fire storm may be obtained by equating the above products.

$$U_0 = \frac{\rho 1}{\rho_0} \frac{w\, r_0}{2z_0} \qquad (1)$$

With environmental temperatures of 300° K. and flame temperatures of 900° K., $\rho_1/\rho_0 \approxeq 1/3$ or

$$U_0 \approxeq \frac{w\, r_0}{6z_0} \qquad (2)$$

If observed values from the pile fires of r_0 = 6 meters, z_0 = 10 meters, and w = 8 m.sec.$^{-1}$ are used, the resulting value of U_0 should be about 0.8 m.sec.$^{-1}$. Such windspeeds could be observed only under calm conditions by very careful checking of flame motion.

If values of w = 20 m.sec.$^{-1}$, r_0 1,200 meters and z_0 = 100 meters for the Hamburg conflagration are assumed, the resulting horizontal wind speed should be approximately 40 m.sec.$^{-1}$. Values of 20 m.sec.$^{-1}$ have been reported near some ground conflagrations. The strongest winds will occur above the surface and will exceed 20 m.sec.$^{-1}$

A simple model for obtaining the rising speed of flame air, w_1, could depict the flame as either a rising balloon of hot air or a vertical cylinder of radius (r_0). At equilibrium, the forces of gravity (g) and drag are equal. For a sphere

$$\triangle\rho g \frac{4\pi r_0^{\,3}}{3} - \rho_0\, \pi r_0^{\,2} w^2 \qquad (3)$$

$$\text{where } \triangle\rho = \rho_0 - \rho_1. \qquad (4)$$

If the values for the pile fires $\triangle\rho/\rho_0 = 2/3$ are used, then

$$w = \left(\frac{\triangle\rho\, g}{\rho_0} \frac{(4r_0)}{3}\right)^{1/2} \approxeq (10\, r_0)^{1/2} \qquad (5)$$

It is doubtful whether the whole flaming area of Hamburg of r_0 = 1,200 m. created one continuous ball, or indeed, if the above equation can be applied to such large areas. Solving the above equation with the pile fire data $w \approxeq 7$ m.sec.$^{-1}$ was anticipated and observed (see section 4.2.2). Finally, a w = 4 m.sec.$^{-1}$ could be expected from the California Project Flambeau fires of r_0 = 160 meters.[13] By use of pulsed radar, w = 20 m.sec.$^{-1}$ was observed.

The vertical motion, w, is not the cause of the fire wind. It is the result of the horizontal pressure gradient ∇p created by the visible flame air and smoke air. Maximum U_0 and ∇p will be created under calm conditions because all of the hot air is above the fire. Increasing gradient winds will cause the hot air column to tilt thereby reducing U_0.

According to Buettner (1967), the general equation for motions can be written as

$$\frac{d(\rho V)}{dt} = -\nabla p \qquad (6)$$

if we neglect friction and Coriolis forces. Simplifying further by having only component u in a

[13] Personal communication with Thomas Y. Palmer, Pacific Southwest Forest and Range Experiment Station, Riverside, California.

vertical flame wall, we have

$$\partial\mu\,(\rho u) / (\partial x) = -(\partial p) / (\partial x) \qquad (7)$$

or integrated

$$\rho u^2 = -\triangle p \qquad (8)$$

if u_g is zero.

The pressure difference ($\triangle p$) between free air and fire, near the surface, is $-\triangle p = z_0 . g \triangle \rho$ where z_0 is flame height. (9)

Using the same data as before, we find $\triangle p = 0.67$ millibars for a flame height of 10 meters. Combining equations 8 and 9, we have the fire storm or into-fire wind as

$$u = (z_0\, g\, \triangle\rho/\rho)^{1/2} \qquad (10)$$

or with $g = 10$ m.sec.$^{-2}$ and $\triangle\rho/\rho = 2/3$

$$u = 2.6\, z_0^{\,1/2}$$

In the Hamburg fire, values of z_0 were in excess of 100 meters resulting in $u_0 = 26$ m.sec. or more.

A more refined theory should take into account:

a. the conical form of smaller fire flames and the consequent ∇p pattern

b. the combination of equations of motions and of conservation of mass

c. the effect of the shrinking diameter through which air moves into the fire if this is essentially a cylinder or a cone

d. the effect of the step-function of u at the fire border where suddenly ρ drops drastically.

4.3. Laboratory Fire

Results of the microanalysis and the average concentrations of major pollutants during burning of the slash samples are given in table 13. These data are especially interesting because the absolute quantities of emissions can be monitored more or less completely, and a carbon balance can be written for each fire. Carbon balances recorded on grassy material burned in the same fashion typically fall between 95 and 99 percent. Since this was the first experiment with logging slash materials, the rather large variations in carbon balance for these fires are largely unexplained.

Trends of temperature from five laboratory fires are shown in figure 18. The temperature curves show different burning characteristics for similar quantities of fuel from the same species. The differences are unexplained and could be due to differences of fuel packing and ignition.

4.3.1. PARTICULATE MATTER

Particulate matter production from the five samples are reported in table 13 as grams of smoke per kilogram of fuel. All samples yielded about the same amount of smoke.

4.3.2. CARBON MONOXIDE AND CARBON DIOXIDE

Cumulative CO_2 production curves are shown in figure 19. For similar species, CO_2 production between samples occurred during the equilibrium burning period. More CO_2 was produced by the western redcedar samples than by western hemlock or Douglas-fir.

Carbon monoxide production from the five samples appeared similar to CO_2 production (fig. 20A).

The ratio of CO to CO_2 from the laboratory fires was similar to the ratio during period I of the broadcast fire (4.1.6.2) and slightly greater than the ratios from the pile fire (4.2.1).

4.3.3. HYDROCARBONS

Production of total hydrocarbons is reported as "C" in table 13. Trends are shown in figure 20B. Hydrocarbon production appeared to be greatest from western redcedar with Douglas-fir second and western hemlock third. Total hydrocarbon production from western redcedar was similar to that from dry native brush and fruit prunings as reported by Darley et al. (1966) and much lower than hydrocarbon production in rice and barley straw.

Individual hydrocarbons from the laboratory fires are shown in table 14. The concentration of individual hydrocarbons obtained from the laboratory samples were essentially the same as those obtained from the broadcast fire (4.1.6.3). Since the hydrocarbon concentrations were similar, the absolute values in grams per kilogram of fuel from the laboratory can be said to estimate hydrocarbon production from the field.

Table 13.—*Laboratory analysis of combustion products from Douglas-fir, western hemlock, and western redcedar slash*[1]

Sample	Sample weight	Microanalysis[2]		Moisture content	Smoke	CO	CO_2	C (hydrocarbons)	$CO:CO_2$	Residue	Carbon balance
		Carbon	Hydrogen								
	Kilogram	*Percent sample weight*		*Percent ovendry weight*	*Grams*[3]					*Grams per kilogram*	*Percent*
Hemlock 1	11.4	63.39	1.82	8.4	2.0	30	1,030	1.2	0.02939	1.9	79
Hemlock 2	12.1	67.65	1.73	8.4	2.0	46	1,213	1.2	.03628	1.6	93
(wood)	–	47.88	6.42	–	–	–	–	–	–	–	–
Douglas-fir 1	8.2	59.67	1.95	7.2	2.3	32	1,143	1.6	.02828	1.5	89
(wood)	–	46.84	6.46	–	–	–	–	–	–	–	–
Western redcedar 1	11.0	62.77	1.90	7.2	1.7	56	1,554	2.2	.03636	1.0	109
Western redcedar 2	11.0	56.98	1.62	7.2	2.2	59	1,395	2.2	.04212	2.9	110
(wood)	–	47.36	6.49	–	–	–	–	–	–	–	–

[1] Analysis by E. F. Darley.

[2] Analysis by Elek Micromanalytical Laboratories, P. O. Box 1156, Walteria Sta., Torrance, Calif. 90505.

[3] Per kilogram of fuel.

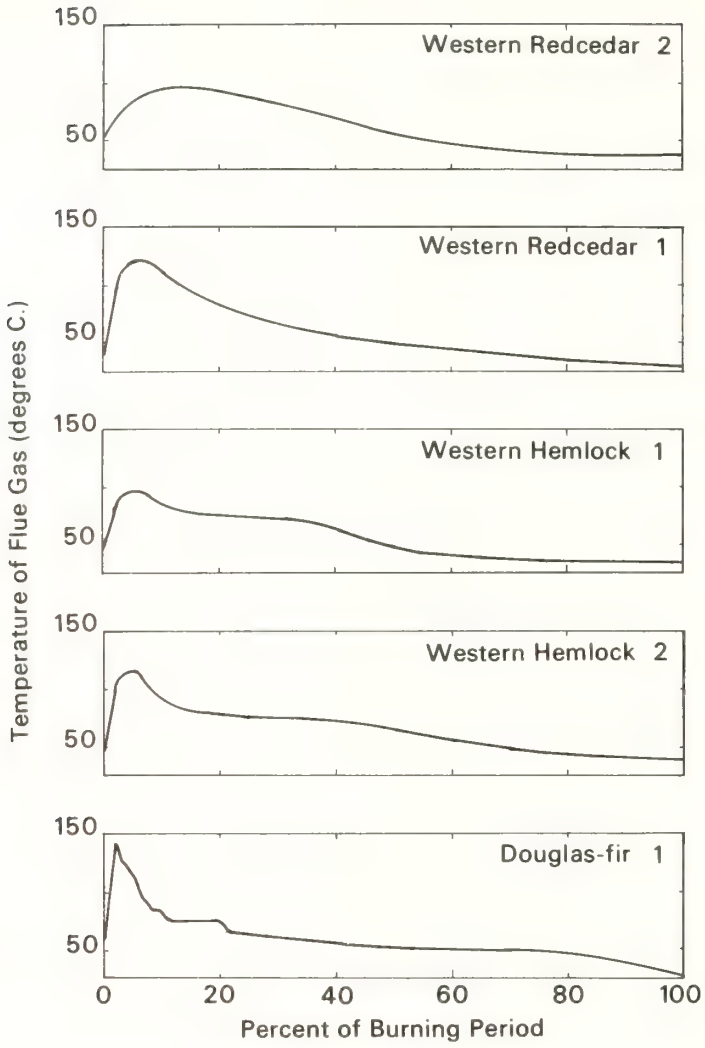


Figure 18. — Gaseous temperature in relation to percent of burning time of fire laboratory samples.

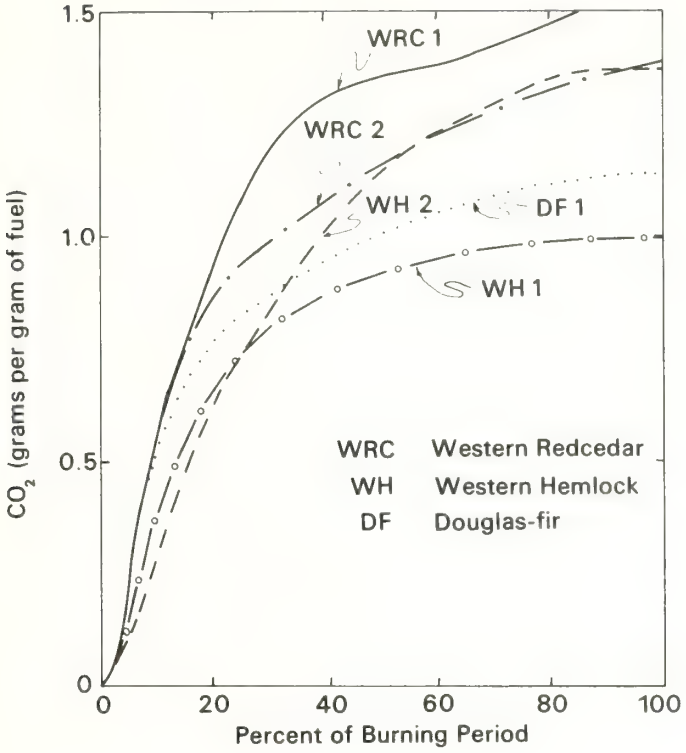


Figure 19. — Cumulative CO_2 production from five laboratory samples.

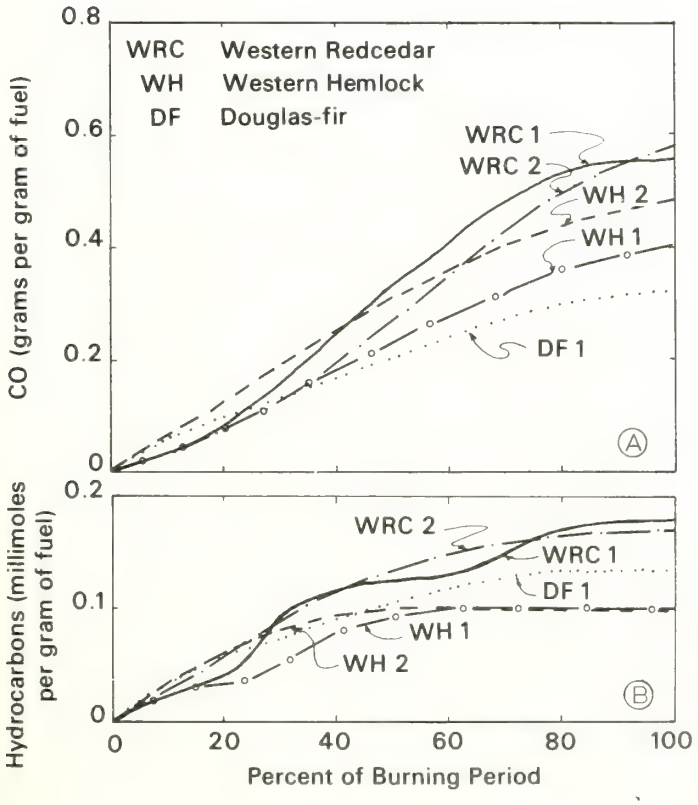


Figure 20. — *A*, Cumulative CO production from five laboratory samples; *B*, hydrocarbon production from five laboratory samples.

Table 14.—*Gas chromatographic analyses of smoke samples from five laboratory fires, by number of minutes after fire start*

Gas	Western hemlock sample No. 1			Western hemlock sample No. 2			Douglas-fir			Western redcedar sample No. 1			Western redcedar sample No. 2		
	2 min.	7 min.	17 min.	1.5 min.	7 min.	18 min.	1 min.	5 min.	16 min.	2 min.	5 min.	16 min.	2.5 min.	8 min.	19 min.
	Parts per million														
Methane	3.2	–	13.2	3.2	4.8	8.3	2.0	0.7	9.3	3.5	5.2	11.2	10.0	4.3	7.8
Ethene	1.0	–	1.4	1.2	.6	.6	.6	.9	1.0	1.3	.8	.9	5.2	.5	.6
Ethane	.1	–	.6	.1	.2	.3	.6	.3	.5	(1)	.3	.4	.7	.2	.3
Acetylene	.6	–	.1	.7	.3	.2	.3	.3	.2	.7	.3	.3	2.5	.1	–
Propane	(1)	–	.4	(1)	2.7	(1)	(1)	.1	.2	(1)	.1	.3	.2	(1)	(1)
Propene	.2	–	.5	.3	.1	.1	.1	.3	.5	.3	.2	.3	1.1	.2	.2
Isobutane	–	–	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)
N-butane	(1)	–	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)
Acetylene	.7	0.1	.5	.8	.2	.1	.5	.3	.2	.8	.3	.3	2.9	.3	.2
1-butene	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	.2	(1)	(1)
Isobutene	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	.1	(1)	(1)
Trans-2-butene	(1)	(1)	(1)	(1)	–	–	–	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)
Isopentane	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)
Cis-2-butene	(1)	(1)	(1)	(1)	–	–	–	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)
N-pentane	–	–	–	–	–	(1)	–	–	–	–	–	–	–	–	–
3-methyl butene-1	(1)	(1)	(1)	(1)	(1)	–	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)
1,3-butadiene	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	.3	(1)	(1)
1-pentene	(1)	(1)	–	–	–	–	(1)	(1)	–	(1)	(1)	(1)	(1)	–	–
2-methyl butene-1	–	–	–	–	–	–	–	–	(1)	–	–	–	(1)	–	–
Trans-2-pentene	–	–	(1)	–	–	–	–	–	–	–	–	–	(1)	–	–
2-methyl butene-2	–	–	–	–	–	–	–	–	(1)	–	–	–	–	–	–

[1] Less than 0.1 p.p.m. Methane, ethane, ethene, and acetylene were analyzed by use of a 5-foot Poropak N column at 60° C. All others were analyzed by use of a 36-foot, 10-percent DMS column at 0° C.

5. DISCUSSION AND CONCLUSIONS

The relationship between the current practice of slash burning and air pollution was investigated with broadcast and pile fires in the field and laboratory fires. The hypothesis tested was that incomplete combustion and consequently greater emissions result from low-temperature fires. In our experiments, the broadcast fires represent low-temperature fires whereas the piles and laboratory fires represent higher temperature fires. These experimental fires were investigated with respect to burning characteristics and gaseous, hydrocarbon, and particulate emissions. The results of each fire are summarized individually.

The broadcast burn was center-fired by power boosters. In 15 minutes, a strong convection column had developed which penetrated a lower inversion at 640 meters and sheared at 1,370 meters. The convection column began to bend over with the prevailing wind 25 minutes after ignition and by 90 minutes after, only disorganized small sources of smoke remained. From photography and meteorological observations, three fire stages were described, the buildup, diedown, and isolated hot spots.

Ground particulate samples indicated an increase of nearly 10 times the background level immediately downwind from the fire during the second stage. The particulates in the smoke plume in the fire vicinity reduced visibility to 0.5 kilometer, but at a distance of 19 kilometers from the fire the visibility had increased to the level found over Seattle.

Similarly, high CO and CO_2 concentrations found at the fire site decreased rapidly to ambient conditions in horizontal and vertical directions. CO:CO_2 ratios increased from 0.034 during the buildup stage to 0.051 during the isolated hot spot stage. CO:CO_2 ratios from 850° C. flames were similar to those from the laboratory fires.

Hydrocarbon analyses of gas samples revealed low concentrations of 25 components, the most significant of which appear to be the low molecular-weight hydrocarbons and alcohols including ethylene, ethane, propene, propane, methanol, and ethanol. Several unsaturated compounds were found, but the quantities were relatively low.

In contrast to the broadcast fire, the pattern of combustion and emission was more uniform in the pile fires. The CO:CO_2 ratios were nearly constant throughout the pile fire and were lower than from the 850° C. flames in the broadcast and laboratory fires.

Analysis of laboratory fires of Douglas-fir, western hemlock, and western redcedar revealed three fire stages: the buildup, diedown, and equilibrium stage. The length of each stage appeared to be related to the total charge, fuel packing, density, and composition. The burning characteristics of the Douglas-fir laboratory fire were similar to the broadcast fire. Analyses of the gases revealed CO and CO_2 emissions similar in magnitude to those from burning other agricultural residue. The total hydrocarbon level appeared to be lower. The CO:CO_2 ratios from the laboratory fires were similar to those from the broadcast fire indicating a similar degree of combustion.

The results of these tests suggest that broadcast fires can be modeled in the laboratory with respect to burning characteristics, gaseous and particulate emissions from different fuel density, packing, and quality and method of ignition. Furthermore, these tests indicate that establishing a high energy fire with a strong convection column under conditions favorable for rapid atmospheric dispersion can minimize the air pollution aspects of slash burning. These conditions may be achieved by a balance of local fire behavior management with meteorological management of smoke.

Fire behavior management includes techniques of fuel modification, electrical ignition and fuel booster systems, and firing sequences, all aimed at obtaining quick, positive ignition and rapid fire development with complete combustion of unwanted fuel.

Meteorological management may include burning under an unstable atmospheric profile, when windspeeds are sufficiently high to advect smoke, and when wind directions are away from populated areas.

Slash burning may have to be done in all seasons: fall, winter, spring, and summer. Yearlong burning may be necessary to obtain enough burning days when the air pollution threat can be minimized by some trade-off between local fire behavior management and meteorological management. In late winter or spring, large fuels may still

have high fuel moistures, and fires of short duration consuming only the smaller fuels – quick, hot fires – will result. In late summer or fall when heavy fuels are dry, residual glowing combustion, as typified by stage III of this study, may result. Total emissions output may be relatively high over long periods of unfavorable dispersal conditions (nighttime subsidence and inversions). Burning early in the day and establishing a high rate of energy release during this more stable period may overcome this type of air pollution threat. Decreasing energy release rates will be offset by increasing atmospheric instability later in the day. Chances of burnout of all available fuels, including the heavy fuels, will be increased.

In general, the concentrations of gases and hydrocarbons found in gas samples taken under field conditions were similar to those taken under laboratory conditions. Concentration of gases and hydrocarbons diluted rapidly to ambient or background values. Particulate emissions in the smoke plume were high but decreased in 20 kilometers to values found over the Seattle area.

In addition to the air pollution aspects, the following significant findings and developments resulted from this research project: The airborne version of the integrating nephelometer used in these studies was developed and flight tested; air samplers, capable of operating without power, were developed to collect air samples over a period of time; the vacuum oven technique proved to be the most reliable and practical method of determining fuel moisture; and the peak frequency of flame speeds was found to be 3 $m.sec.^{-1}$.

6. SUMMARY

This is a report on an investigation, conducted under a grant from the U.S. Forest Service to the University of Washington, of the current practices of slash burning in relation to air pollution.

The hypothesis was that incomplete combustion and greater emissions result from low-temperature fires. Low-temperature fires were associated with broadcast burns. Piled slash was expected to burn more completely and at higher temperatures; hence, would produce less pollution. The results of field tests were compared with laboratory burns with respect to burning characteristics and gaseous and particulate emissions.

The more salient conclusions are:

1. Ground level particulates increased to nearly 10 times the background immediately downwind from the broadcast burn. The particulates in the smoke plume in the vicinity of the fire reduced visibility to 0.5 kilometer, but at a distance of 19 kilometers from the fire, the visibility had increased to the level found over Seattle.

2. Similarly, high CO and CO_2 concentrations found at the fire site decreased rapidly to ambient conditions in horizontal and vertical directions.

3. Hydrocarbon analyses of gas samples revealed low concentrations of 25 components, the most significant of which appeared to be the low molecular weight hydrocarbons and alcohols including ethylene, ethane, propene, propane, methanol, and ethanol. Several unsaturated components were found but the quantities were relatively low.

4. Results suggest that broadcast fires can be modeled in the laboratory with respect to burning characteristics, gaseous and particulate emission from different fuel density, packing, composition, and method of ignition.

5. Air pollution aspects of slash burning can be minimized by a high energy release rate fire with a strong convection column under conditions favorable for rapid atmospheric dispersion. The fire should be of short duration to consume the smaller fuels only.

7. FUTURE RESEARCH

Areas of additional research, suggested as a result of this project, are:

1. Ignition systems for different fuels, weather, and topography to minimize air pollution.
2. Fuel booster systems to achieve rapid high temperature and rate of energy release build-up.
3. Practical methods of energy budget analyses to aid in decisionmaking of prescribed burning time and technique.
4. Climatological study of potential temperature surfaces and drift patterns to aid in scheduling burning.
5. Economic analyses of alternative burning techniques.

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9. APPENDIX

9.1. Carbon Monoxide and Carbon Dioxide Data

9.1.1. BROADCAST FIRE

Table 15.—*Analysis of CO and CO_2 collected in water-displacement air samplers during broadcast burn, Pack Forest, June 25, 1968*

Location	Period I		Period II		Period III	
	CO	CO_2	CO	CO_2	CO	CO_2
	Parts per million					
A 1	8	450	–	450	–	–
A 2	–	–	–	–	–	–
A 3	6	427	8	697	2	337
B 1	7	495	17	517	8	517
B 2	2	427	7	585	7	630
B 3	7	495	6	526	7	630
C 1	–	–	–	–	11	540
D 1	11	549	26	531	–	–
D 2	2	1,080	6	495	8	607
D 3	2	472	6	436	11	630
E 1	12	697	13	607	8	607
F 1	–	517	2	382	8	463
F 2	8	562	11	508	7	427
F 3	2	450	–	–	6	855
G 1	6	487	20	832	2	684
H 1	–	–	–	495	6	405
H 2	6	495	–	470	8	463
H 3	–	–	–	–	–	–
I 1	6	472	40	607	2	427
J 1	8	720	23	796	–	–
J 2	11	729	13	679	–	–
J 3	–	495	–	967	–	540
K 1	–	–	23	832	–	–
L 1	2	607	23	675	8	742
L 2	2	427	13	1,057	8	463
L 3	8	517	8	720	2	526
M 1	8	508	6	675	7	391
N 1	–	607	13	430	5	517
N 2	–	405	–	–	–	–
N 3	6	517	6	495	–	–

9.1.2. PILE FIRE

Table 16.—*CO and CO_2 concentrations in samples taken during pile fire, Pack Forest, July 11, 1968*

Line 1[1]			Line 2[1]			Line 3[1]		
Time sample started[2]	CO	CO_2	Time sample started[2]	CO	CO_2	Time sample started[2]	CO	CO_2
	Parts per million			*Parts per million*			*Parts per million*	
1237	0	449	1240	–	([3])	1239	6	972
1247	–	([3])	1250	2	671	1248	–	([3])
1255	1	416	1258	–	([3])	1325	5	578
1307	–	([3])	1308	1	578	1333	25	1,318
1314	1	462	1318	5	578	1340	–	([3])
1321	10	671	1325	2	419	1348	1	439
1327	25	430	1333	5	487	1355	45	1,041
1335	25	763	1340	2	449			
1343	2	763	1347	2	449			
1353	0	462	1402	1	462			

[1] Location of sample lines shown in figure 5.
[2] Average sample period was 7 minutes.
[3] Sample container destroyed by heat from fire.

9.2. Conversion Factors

1 centimeter (cm.)	=	0.0394 in.
1 inch (in.)	=	2.54 cm.
1 meter (m.)	=	3.28 ft.
1 foot (ft.)	=	0.305 m.
1 kilometer (km.)	=	0.621 stat. mi.
1 stat. mi.	=	1.609 km.
1 hectare (ha.)	=	2.471 acre
1 hectare (ha.)	=	10^4 m.^{2}
1 liter (l.)	=	0.264 gal.
1 gallon (gal.)	=	3.785 l.
1 meter per second (m.sec.$^{-1}$)	=	2.236 m.p.h.
1 mile per hour (m.p.h.)	=	0.447 m.sec.$^{-1}$
1 gram (g.)	=	0.00220 lb.
1 pound (lb.)	=	453.6 g.
1 metric ton (5)	=	1.102 short ton
1 short ton	=	907.2 kg.
1 cal.	=	0.00397 B.t.u.
1 B.t.u.	=	252 cal.

Fritschen, Leo; Bovee, Harley; Buettner, Konrad; and others.

1970. Slash fire atmospheric pollution. USDA Forest Serv. Res. Pap. PNW-97, 42 pp., illus. Pacific Northwest Forest & Range Experiment Station, Portland, Oregon.

Results of an investigation of slash burning in relation to air pollution conducted under a grant, U.S. Forest Service to the University of Washington, are presented. The hypothesis: Incomplete combustion and greater emissions result from low temperature fires associated with broadcast burns. Results of field tests and laboratory tests with respect to burning characteristics, gaseous and particulate emissions are reported.

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GPO 697-341

9.1.

Tim
st

[1] Loca
[2] Aver
[3] Samp

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AN ECONOMIC ANALYSIS OF ACCELERATED ROAD CONSTRUCTION ON THE BUREAU OF LAND MANAGEMENT'S TILLAMOOK RESOURCE AREA

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A BRIEF SUMMARY OF STUDY

This report assesses the economic consequences of advance roading (accelerating road construction) in order to increase thinning receipts in managing young growth on the U.S. Department of Interior, Bureau of Land Management's Tillamook Resource Area (about 50,000 acres).

Alternative Rate of Road Construction Economically Inferior to Current Program

Presently, approximately 15 miles of logging roads are being constructed annually. At this rate, the entire system will require 16 years to complete. The base program--15 miles per year--was compared with a plan to double the rate of road construction. The 30-mile-per-year construction program was found to be economically inferior to the base program. In fact, investment in such an accelerated program would earn a minus 1.25-percent rate of return. Although advance roading would increase timber production and timber revenues, the additional revenues would not be enough to compensate for higher maintenance, timber sale administration, and interest charges.

Current Rate of Road Construction Supports an Active Thinning Program

The present pattern of logging has a major effect on the economic feasibility of accelerating road construction in the Tillamook Resource Area. The road system will be completed sooner as a result of logging staggered settings rather than a continually receding wall of timber. That is, the current rate of road construction is providing more road than necessary to market the annual allowable cut. In a real sense, therefore, the current rate is "advance" roading, since timber units between staggered settings support an active thinning program.

Accelerated Roading Not Economically Feasible Despite Changes in Assumptions

Basic costs and price assumptions were varied systematically, and the effects of such changes upon the economics of advance roading were examined. For example, reduction in road construction costs would not significantly affect the economic attractiveness of advance roading. Furthermore, increasing stumpage values for thinning would still generate a negative rate of return.

Increasing all costs and revenues 3 percent, compounded annually to simulate inflation, significantly affected the economic feasibility of advance roading. But the rate of return (1.92 percent) does not compare favorably with alternative public investment opportunities.

ADVANCE ROADING--A MEANS FOR INCREASING ALLOWABLE CUT

Since about 1960, public forests in western Oregon and western Washington have been marketing their full annual allowable cut. Because a strong demand for timber is forecasted and because public forests are expected to produce a larger proportion of the region's future log production, public forest managers are exploring alternatives to increase allowable cuts.

Advance roading has been suggested as a means for achieving greater timber production.[1/] [2/] It would result in increased harvest from prelogging small timber and salvaging mortality in old growth, plus thinning young growth (fig. 1). For example, Fedkiw estimated that between 1960 and the year 2000, an additional 100 billion board feet could be utilized in the Douglas-fir region of Oregon and Washington if road construction were accelerated.

To justify advance roading, revenues from additional timber harvests must cover added interest, maintenance, and administrative costs. Depending upon an agency's or firm's guiding rate of interest, previous analyses of both private and public forest ownerships have shown that advance roading can be economically attractive. In an analysis of private investment, Fedkiw reported "rates of return as high as 10 percent, after taxes. . ." (p. 5),[3/] but Payne found that public investments in advance roading earned between 2.9 and 3.6 percent.[4/]

This study gives public forest managers an indication of the economic feasibility of advance roading for managing young-growth timber. It is unique because it considers a situation where thinning yields are the only timber benefits of advance roading. Previous studies have involved either (1) just prelogging and mortality salvage operations in old-growth stands, or (2) a combination of (1) and thinning of young-growth stands.

[1/] Fedkiw, John. Advance roading for increased utilization in the Douglas-fir region--Oregon and Washington. Western Forest. & Conserv. Ass. Proc.: 51:64-69. 1960.

[2/] USDA Forest Service. Timber trends in the United States. Dep. Agr. Forest Resource Rep. 17, 235 pp., illus. 1965.

[3/] See footnote 1.

[4/] Payne, Brian R. An economic analysis of alternative rates of investment in National Forest road construction: the North Umpqua case. 190 pp., illus. 1969. (Unpublished Ph.D. dissertation on file at Univ. Calif., Berkeley.)

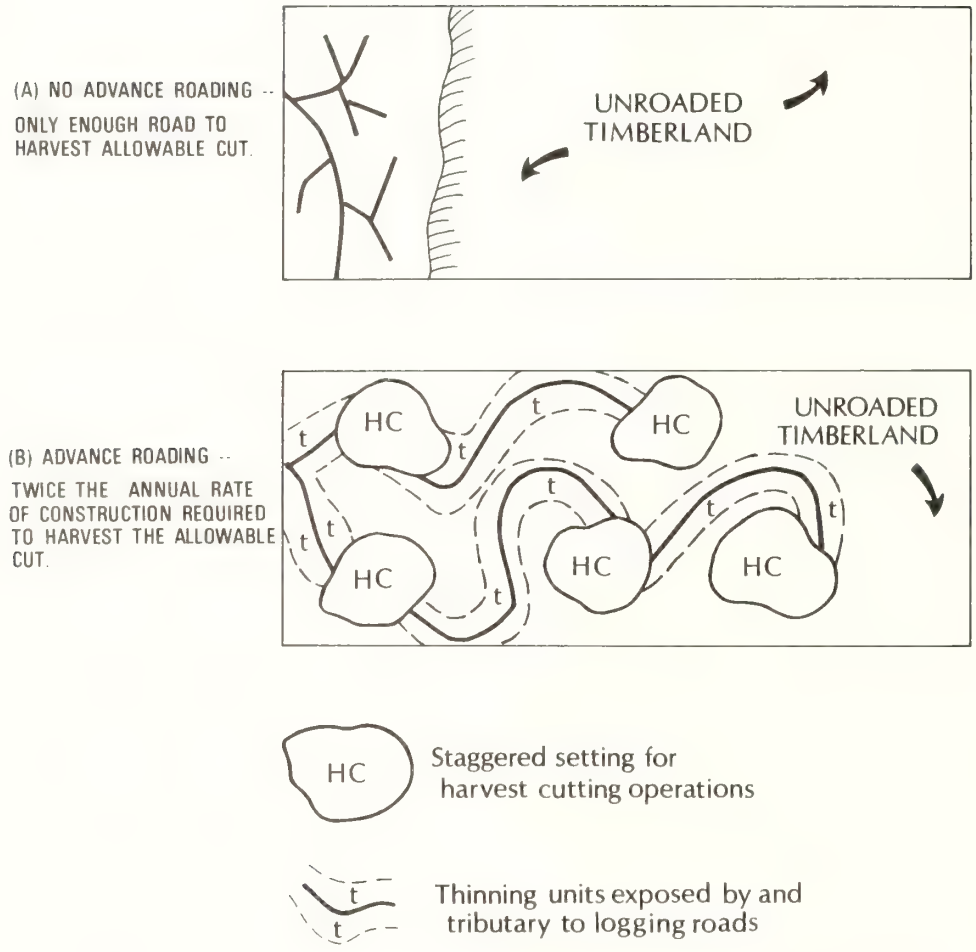
(A) NO ADVANCE ROADING --
ONLY ENOUGH ROAD TO HARVEST ALLOWABLE CUT.
UNROADED TIMBERLAND
(B) ADVANCE ROADING --
TWICE THE ANNUAL RATE OF CONSTRUCTION REQUIRED TO HARVEST THE ALLOWABLE CUT.
HC
t
UNROADED TIMBERLAND
Staggered setting for harvest cutting operations
Thinning units exposed by and tributary to logging roads

Figure 1.—Harvesting the annual allowable cut from a continually receding "wall of timber" (A) requires less road construction than advance roading (B).

This analysis of young-growth advance roading opportunities was conducted in conjunction with the U.S. Department of Interior, Bureau of Land Management's (BLM) Tillamook Intensive Management Project[5/] (fig. 2). Here, 196 miles of roads were completed or under contract for construction by December 31, 1967. An additional 300 miles of road will be required to complete the Tillamook project road system. However, only an additional 240 miles will be required in the near future since timber on some scattered, inaccessible tracts will not be merchantable for another 25 to 30 years.

Approximately 42 percent of the resource area's 52,000 acres of forest land is now accessible for logging operations (i.e., "roaded"). At the end of calendar year 1967, 4,563 acres, or 48 percent, of the Tillamook Resource Area's acreage of rotation age (80 years) or older conifer timber type was accessible by road. Of this, approximately 65 percent has been clearcut. Because of the heterogeneous composition of age classes, roads constructed to provide access for clearcutting mature timber also exposed young growth (table 1). This study focuses on the accessibility of thinnable timber. Thinnable timber here is fully stocked, 40- to 70-year-old conifer--mostly Douglas-fir--stands, 60 percent of normal basal area and greater, on slopes less than 45 percent. It is the potential yield from presently inaccessible thinnable stands that will determine the economic feasibility of accelerating road construction. Currently, about 57 percent of the thinnable acreage is inaccessible by road (i.e., "unroaded"). At the present rate of road construction, 15 miles per year, this acreage will not be fully accessible for 16 years.

COMPILATION OF BASIC DATA

The major difference between the base (15 miles per year) and the accelerated (30 miles per year) programs from a construction cost standpoint is the timing and not the amount of investment. That is, the total cost of road construction was assumed to be the same--$8,824,000--regardless of how quickly the road system was to be completed. In contrast, both timing and amount of timber harvesting activity varied by road plan. The methods for deriving annual timber revenues and costs are reviewed in this section.

Simulation of Road Construction and Timber Harvesting Involved Three-Phase Mapping of Study Area

Determining the acreage of timber type, by species, age, and stocking classes, tributary to new road construction was the major data compilation task. Timber type tributary to and construction costs of the first additional

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[5/] This project was undertaken in 1962 to field test various silvicultural, engineering, and administrative procedures for managing young-growth Douglas-fir forests. The Production Economics Research Work Unit of this Station is assisting the Bureau of Land Management with evaluation phases of this study.

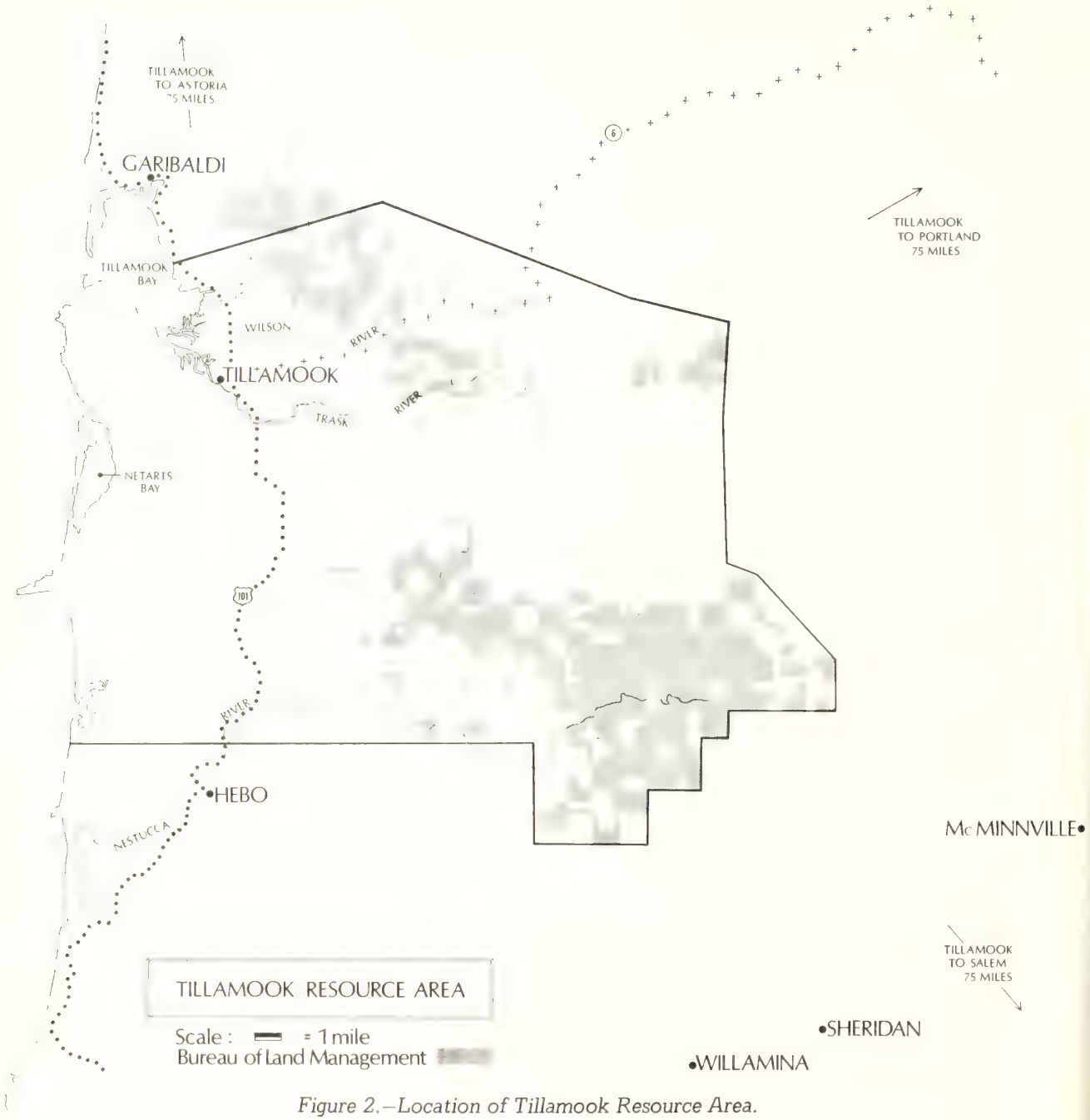

Figure 2.—Location of Tillamook Resource Area.

Table 1.--*Acres of accessible commercial forest land on Tillamook Resource Area in 1967, by forest type and stocking class*[1/]

Age class	Douglas-fir stocking class[2/]			Alder (all stocking classes)	Total
	10-39	40-69	70+		
0-10	156 (56)	603 (70)	4,874 (100)	262 (56)	5,895 (94)
20	29 (60)	239 (44)	167 (31)	143 (23)	578 (36)
30	19 (100)	110 (53)	962 (59)	411 (40)	1,502 (54)
40	15 (68)	149 (45)	750 (44)	908 (32)	1,822 (38)
50	32 (48)	58 (55)	89 (12)	105 (7)	284 (23)
60	40 (10)	125 (15)	1,648 (37)	103 (6)	1,916 (33)
70	85 (19)	435 (31)	5,902 (47)	105 (9)	6,527 (45)
80+	(3/)	(3/)	1,581 (24)	3/ 47 (11)	1,628 (24)
All classes	438 (19)	2,596 (43)	15,034 (49)	2,084 (21)	20,152 (42)

1/ Numbers in parentheses indicate percentage of type class accessible. Not included are 1,515 acres of nonstocked forest land.

2/ Stocking is expressed as percent of crown closure.

3/ For purposes of this study, all acreage in the 80+ age class was shown as 70 percent or better stocked even though in actuality there is a limited acreage of lower stocking classes.

mile of road could not be assumed the same as for the last mile in the system. Variability of topography and distribution of forest types, plus the fact that a concerted effort is underway to expose thinnable age classes first, required mapping the uncompleted road system and tributary thinning and harvest cutting units.

Tributary forest acreage could have been determined for each of the remaining 240 miles of road to be constructed in the near future. But such precision was believed unwarranted. Instead, road construction was arbitrarily divided into three phases. Years to complete each construction phase varied by road plan as follows:

	Rate of road construction (miles per year)	
	15	30
Years per phase of construction:		
I	4.7	2.3
II	4.7	2.3
III	6.6	3.4
Total years to complete road system	16.0	8.0

The first two phases each involved 70 miles of road, and the last 100 miles. Classification of the 240 miles of road by phase and type of logging road[6/] is shown below:

Phase of construction	Miles to be completed, by type of logging road		
	Access road	Low design-speed road	Total
I	59.6	10.4	70.0
II	5.4	64.6	70.0
III	11.0	89.0	100.0
Total	76.0	164.0	240.0

Although more road is to be constructed in phase III than during phase I, the first phase accounts for the largest single share of the road investment--43.6 percent versus 33.7 percent. The reason is that considerably more mileage of high cost access road is constructed during phase I than during phase III (access roads cost $60,000 per mile, whereas low design-speed roads only $26,000).

As with road construction investment, the amount and composition of forest land exposed by roads varied from phase to phase. Generally speaking, cutting units exposed by early construction contain more conifer type as well as total acres than later construction (table 2). Also, early construction tapped more thinnable timber.

[6/] Schallau, Con H. An analysis of two logging road standards for BLM's Tillamook project. Pacific Northwest Forest & Range Exp. Sta. USDA Forest Serv. Res. Note PNW-48, 5 pp. 1967.

Table 2.--*Total commercial forest land exposed by three phases of road construction, by type and age*[1/]

(In acres)

Stand age[2/]	Douglas-fir, by phase of construction			Alder, by phase of construction		
	I	II	III	I	II	III
10	50	67	176	63	—	34
20	43	124	270	81	31	90
30	148	212	345	47	107	197
40	186	436	513	335	807	585
50	41	4	417	120	182	1,038
60	828	2,106	805	283	201	950
70	3,198	3,287	1,270	248	180	504
80+	2,339	1,386	1,221	310	33	67
Total	6,833	7,622	5,017	1,487	1,541	3,465

[1/] Not included are 691 acres of nonstocked forest land, of which 65 percent are exposed in phase III.

[2/] Age at beginning of investment period. All stands were updated at beginning of second decade.

Costs and Revenues Assessed for 16-Year Investment Period

Data for the economic analysis of advance roading consist of the differences in costs and revenues between the 15-mile-per-year (16 years) and 30-mile-per-year (8 years) road programs.[7/] Comparisons were limited to a 16-year investment period. Thinning during the 16-year investment period will influence future yields. But the difference in timing and amount of thinning under the two road programs is not great. Later, when certain basic study assumptions are relaxed, we shall see that what happens after the 16th year has no significant effect upon the economic feasibility of advance roading.

[7/] The model for simulating road construction and timber harvesting, and for determining associated costs and revenues, was coded by Ed Holt, mathematician with the PNW Station, in FORTRAN IV for a Control Data Corporation (CDC) 6400 computer. A flow chart and program listing can be requested from the Director, Pacific Northwest Forest and Range Experiment Station, P. O. Box 3141, Portland, Oregon 97208.

Figure 3 shows the basic steps involved in compiling annual costs and returns. Both road right-of-way (step 1) and thinning harvest (step 2) volumes are determined before harvest cut volume (step 4). For example, although the conifer allowable cut in 1967 was 34.7 million board feet,[8/] not all of this volume is allocated to harvest cutting. Some of the volume removed from thinning and road rights-of-way is included in the allowable cut. That is, the allowable cut is composed of three elements: (1) harvest cutting, (2) road right-of-way timber, and (3) "chargeable" thinning (fig. 4).

Because volume from all clearcutting operations--road rights-of-way as well as harvest cutting operations--is considered part of the annual allowable cut, timing of road construction affects the timing of harvest cutting during the 16-year investment period. The faster roads are constructed, the sooner road right-of-way timber will be harvested. Therefore, because the allowable cut is administratively fixed, that apportioned to final harvest cutting from an accelerated roadbuilding system would be less during the initial years of the investment period than from the base road plan. Appendix A describes how the acres to be clearcut for road rights-of-way and those accessible for thinning and harvest cutting were calculated.

Total Volume Harvested During 16-Year Investment Period Differs Little Between Plans

Volumes logged from road rights-of-way and harvest cutting units were calculated from yield tables shown in appendix table 9. Unlike thinning and harvest cutting units, which include only merchantable types, roads cross a full range of age and forest type classes. Therefore, some conifer and hardwood logs from road rights-of-way are too small to sell. But regardless of the merchantability of road right-of-way timber, all conifers 10-inch d.b.h. and larger are chargeable to the allowable cut.

A 10-year cutting cycle was assumed when thinning volume was calculated for each road plan. That is, all accessible thinnable stands were programed for thinning once per decade. The yield table and procedure used to determine acreage available annually for thinning are shown in Appendixes B and C.

Current BLM guidelines stipulate stands be thinned to the lesser of the following: removal of (1) 30 percent of existing basal area or (2) 60 percent of normal basal area. Doing so increases total yield during a rotation. However, the final harvest can be reduced by thinning. If so, the reduction in final harvest volume is "charged" as allowable cut and arbitrarily prorated at the time of thinning. Consequently, other things being equal, the more chargeable thinning in a particular year, the less allowable cut allocated to final harvest cutting operations.

[8/] An allowable cut was calculated for this study. The Tillamook Resource Area does not have an official quota separate from that of the Columbia Master Unit of BLM's Salem District.

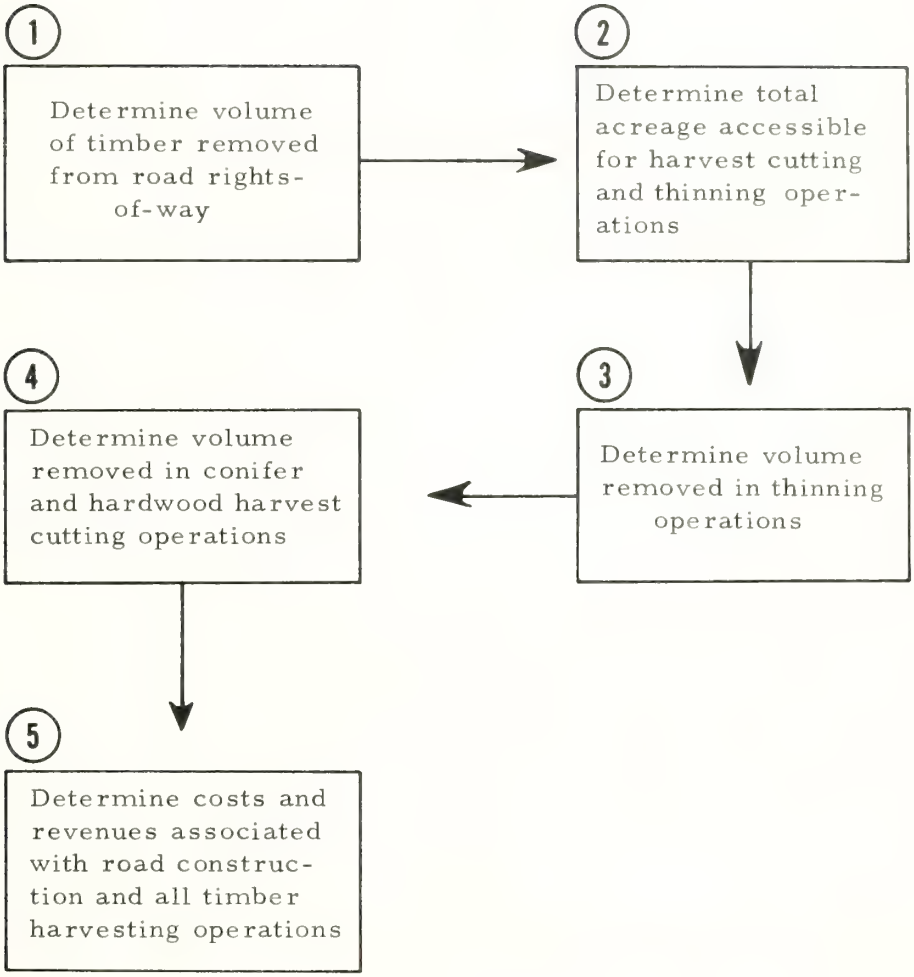
1
Determine volume of timber removed from road rights-of-way
2
Determine total acreage accessible for harvest cutting and thinning operations
3
Determine volume removed in thinning operations
4
Determine volume removed in conifer and hardwood harvest cutting operations
5
Determine costs and revenues associated with road construction and all timber harvesting operations

Figure 3.—Basic steps involved in deriving annual cost and revenue associated with road construction and timber harvesting activities on Tillamook Resource Area.

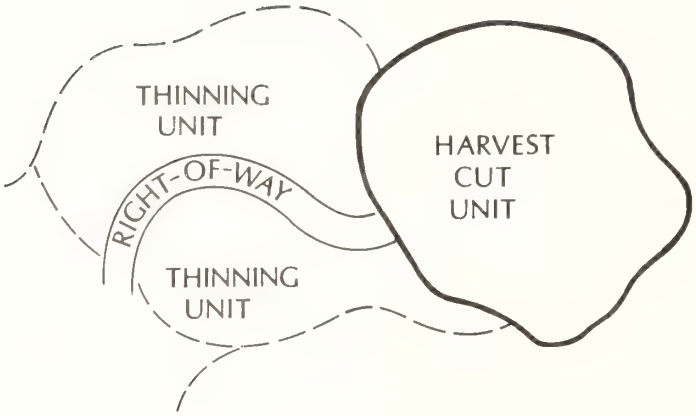

Figure 4.—The allowable cut is composed of (1) all volume removed from the harvest unit and (2) the road right-of-way, and (3) a fraction of the volume from thinning units.

An important observation is that a relatively large amount of thinning could be undertaken without building more roads in the Tillamook Resource Area. Approximately 5,000 acres were accessible for subsequent periodic thinning at the end of calendar year 1967. Total additional acreage exposed and thinned during the first decade would be 4,660 acres in the case of the 15-mile-per-year plan and 5,955 acres for the 30-mile plan. But by the end of the 16-year investment period, total acres initially thinned would be the same for both plans.

The "oldest-first" rule was used in scheduling harvest cutting operations. In addition, within age classes, lightly stocked stands were given precedence over more heavily stocked stands. As has been mentioned, the allowable cut allocated to final harvest cut operations is computed after deducting right-of-way and "chargeable" thinning volumes (see Appendix D for example of how the harvest-cut portion of the annual allowable cut is allocated to various age and stocking classes).

Figure 5 compares the two road programs regarding amount, timing, and composition of the conifer timber harvesting activity during the 16-year investment period. The most significant difference is the composition of the 34.7 million board-foot annual allowable cut. This difference results mainly from the timing of road right-of-way clearing.

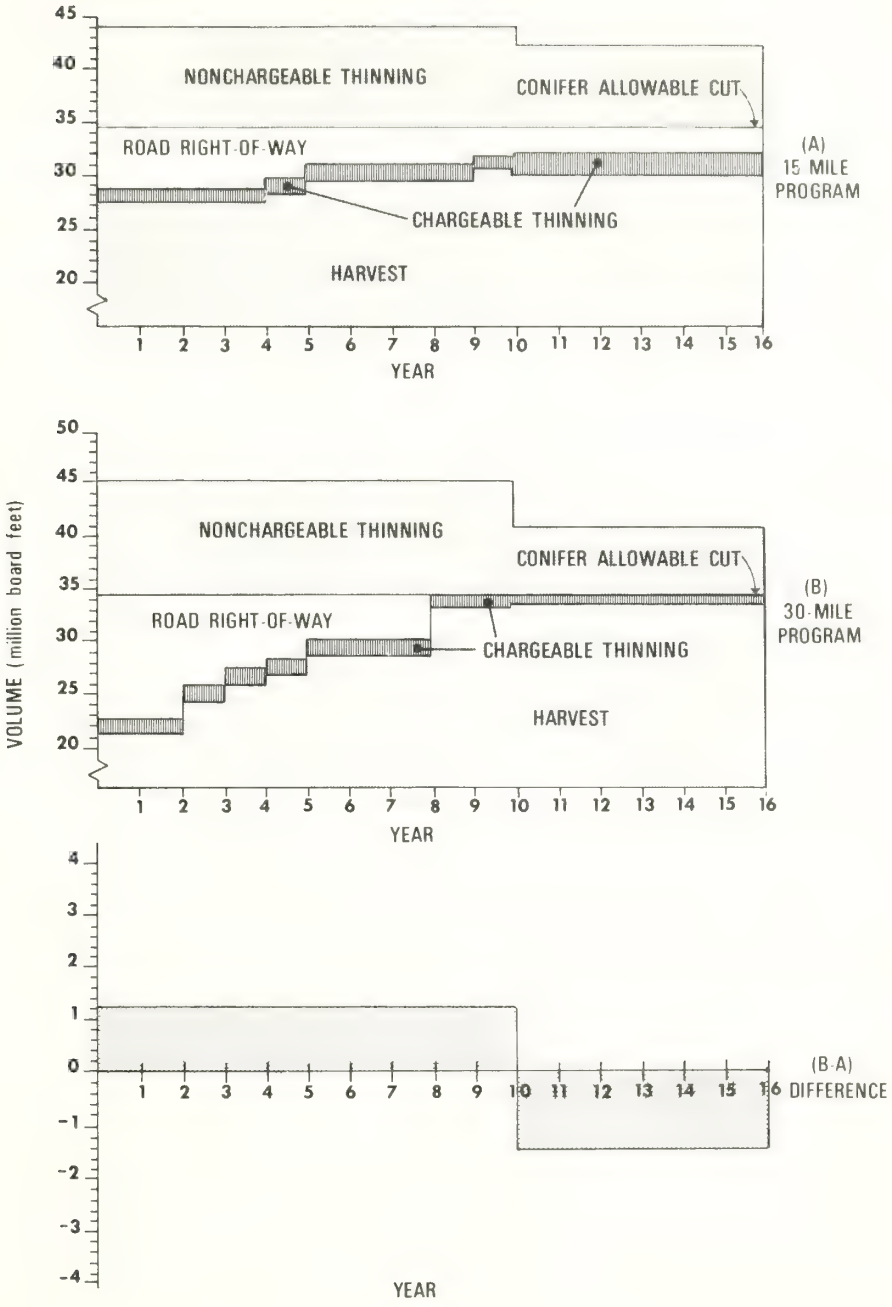

Figure 5.—Comparison of the volume, timing, and composition of conifer timber production under two road plans: 15 miles per year (A), and 30 miles per year (B); and the net differences between the plans (B-A).

The 30-mile program would generate slightly more conifer timber volume over the 16-year period--698 million board feet compared with 694 million board feet for the 15-mile program. However, from an economic standpoint, the composition and timing of the various allowable cut components are perhaps as important as the absolute difference in timber production. For example, the 30-mile program gains an economic advantage during the initial years of the investment period. A dollar of revenue accruing during the first years of the investment period would be worth more than the discounted value of a dollar revenue received several years later. Consequently, the physical relationship shown in figure 5 understates the economic advantage of the 30-mile over the 15-mile program.

Costs and Revenues Based on Tillamook Field Office Experience

Cost and revenue data used in the economic analysis of advance roading were developed from records maintained at the Tillamook field office. These data are shown in tables 3 and 4. Although certain data sources were fragmentary, the range of values used were considered representative of the end of calendar year 1967. Later, we shall examine the consequences of relaxing certain cost and revenue assumptions.

Only cost and revenue categories which vary with the rate of road construction and associated timber production activities were used in this analysis. These included all stumpage revenue but excluded certain operating costs. Not included, for example, were fixed office overhead costs. Costs for maintaining capital improvements as of the end of December 1967 (mainly roads) were also excluded.

Stumpage values synthesized from BLM records shown in table 4 are self-explanatory. Note that thinning sales are of two kinds; initial entry and first reentry. A limited acreage of the resource area was thinned prior to 1967 and would qualify for thinning again during the first decade. However, for the purposes of this analysis, we assumed no reentry thinning would be conducted until the second decade--after 1977.

A comparison of the various costs for the 15- and 30-mile programs is shown in figure 6. Total costs over the 16-year investment period were about the same for both programs--$12.3 million versus $12.9 million. Road maintenance costs accounted for most of the difference.

Road construction accounted for a major share of total costs--about 70 percent--for both programs, but the timing of this expenditure differed considerably. For the 30-mile program, all construction costs accrued during the first 8 years, whereas such costs were distributed over 16 years in the case of the 15-mile program. The difference in total discounted costs are greater than the absolute cost differentials shown in figure 6.

Table 3.--*Costs associated with road construction and harvesting in Tillamook Resource*

Cost item	Unit of measure	Unit cost
Road construction:		
Access roads	Per mile	$60,000.00
Low design-speed road		26,000.00
Road maintenance:		
Access roads	Per mile, per year	500.00
Low design-speed road		1,000.00
Timber sale administration:[1/]		
Harvest-cut sales	Per thousand board feet, Scribner scale, to 5-inch top	2.50
Road right-of-way sales		2.50
Thinning sales:		
40 years old		4.25
50 years old		3.75
60 years old		3.25
70 years old		2.75
80 years old		2.25
Regeneration	Per acre	22.75

[1/] Includes management planning, precruise and layout, cruise and appraisal, and contract preparation and administration.

Table 4.--*Stumpage values used to compute revenues from logging operations, by type of sale*[1/] [2/]

Stand age	Clearcut sales			Thinning sales[3/]	
	Conifer, stocking class		Alder	Initial entry	First reentry
	10-69	70+			
	Dollars per board feet				
40	20.00	25.00	2.50	20.00	—
50	25.00	30.00	5.00	25.00	30.00
60	30.00	35.00	7.50	30.00	35.00
70	35.00	40.00	10.00	35.00	40.00
80	40.00	45.00	12.50	40.00	45.00
90+	--	50.00	--	--	--

[1/] Assumes Scribner log scale to 5-inch top.

[2/] Stumpage calculated as if roads were in place because all construction costs are treated separately.

[3/] First reentry stumpage is higher than initial entry because of lower logging costs.

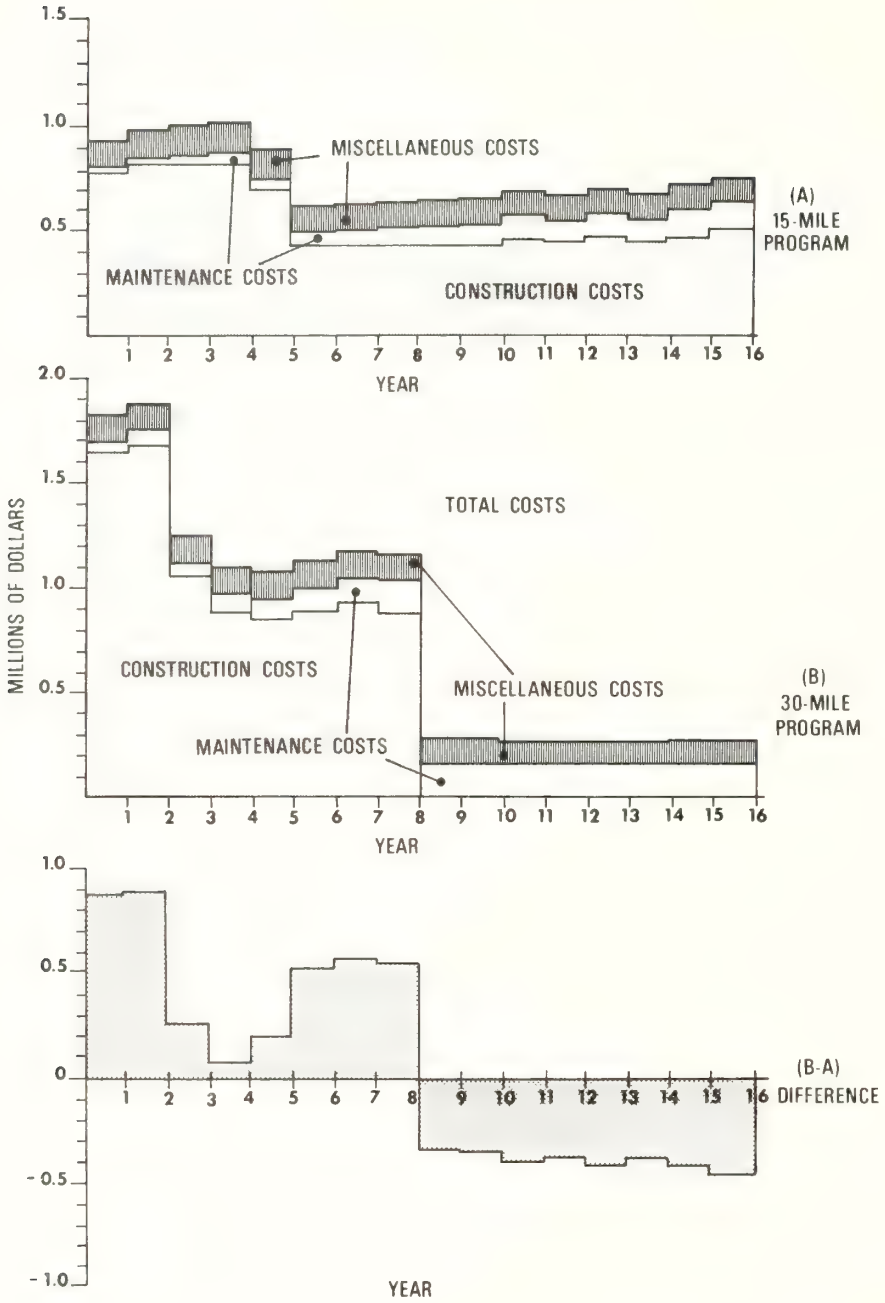

Figure 6.—Comparison of costs — road construction and maintenance, miscellaneous timber sale and reforestation, and total — under two road plans: 15 miles per year (A), and 30 miles per year (B), and net difference in total costs between the plans (B-A).

Total stumpage revenues, like total costs, were slightly less for the 15-mile program than for the 30-mile plan--$30.2 million and $30.4 million, respectively (fig. 7). Unlike costs, stumpage revenues were quite evenly distributed over the 16-year investment period for both programs. Note that although the 30-mile program generated more thinning revenue during the first 2 years than did the 15-mile program, the difference was not sufficient to compensate for lower harvest cut revenues. Consequently, total annual revenues were more for the 15- than the 30-mile program. Total revenues for the 30-mile program were also less for years 11, 12, 15, and 16. When coupled with lower initial construction and maintenance costs, the early revenue advantage of the 15-mile plan over the 30-mile plan is of particular importance from a present value standpoint.

ECONOMIC EFFICIENCY OF ALTERNATIVE ROAD PROGRAMS

The relative economic efficiency of the advance roading alternative compared with the base program was measured by the internal-rate-of-return criterion.[9/] The internal rate of return earned by the additional road investments is the discount rate that equates the present value of incremental revenues to the present value of incremental costs. In other words, it is the rate which solves the following equation:

$$0 = \left[\begin{array}{c}\text{Sum of discounted}\\ \text{incremental}\\ \text{revenues}\end{array}\right] - \left[\begin{array}{c}\text{Sum of discounted}\\ \text{incremental}\\ \text{costs}\end{array}\right]$$

or,

$$0 = (PVR_{30} - PVR_{15}) - (PVC_{30} - PVC_{15}).$$

where PVR_{30} = present value of revenues of the accelerated road program,

PVR_{15} = present value of revenues of the base, or 15-mile road program,

PVC_{30} = present value of costs of the accelerated program,

PVC_{15} = present value of costs of base program.

The only data required for the rate-of-return analysis are the differences (B - A) shown in figures 6 (costs) and 7 (revenues).

[9/] An internal-rate-of-return computer subroutine was used: Chappelle, Daniel E. A computer program for evaluating forestry opportunities under three investment criteria. Pacific Northwest Forest & Range Exp. Sta. USDA Forest Serv. Res. Pap. PNW-78, 64 pp., illus. 1969.

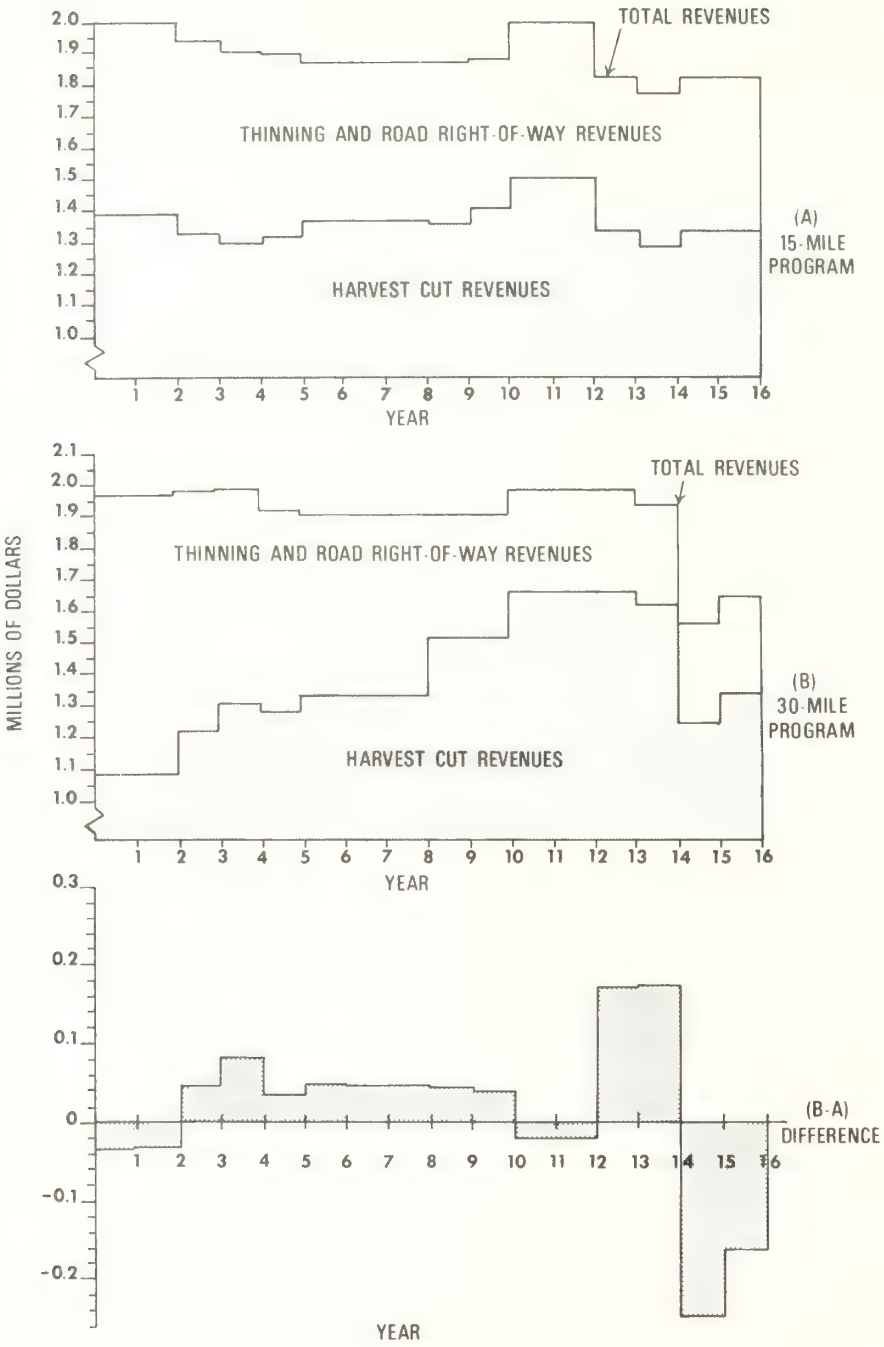

Figure 7.—Comparison of thinning and road right-of-way timber revenues, harvest cut revenues, and total revenues under two road plans: 15 miles per year (A), and 30 miles per year (B), and net difference in total revenues between plans (B-A).

Accelerated Road Program Economically Inferior to Base Program

Results of the economic analysis show the accelerated road construction program to be economically inferior to the current rate of road construction.[10] Incremental costs of undertaking an accelerated program would earn a minus 1.25-percent rate of return.

These results may seem incongruous in light of earlier studies, particularly those involving private lands. However, the findings are not too surprising when one considers that (1) public investment does not involve savings associated with tax treatment of private costs (i.e., private landowners can "expense" maintenance costs and amortize some construction costs), and (2) the "staggered" setting logging technique presently used by BLM requires that roads be constructed sooner than if a continually receding wall of timber were being logged. In essence, the results of this study show that, for the Tillamook Resource Area, wider spacing of staggered settings would not be economical.

Economic Effect of Changes in Basic Assumptions

Several kinds of questions can be raised regarding the results of this study. For example, how might lower road costs influence the results? How might inflationary trends affect the results? Would higher stumpage revenues for thinning enhance the economic feasibility of advance roading? A number of analyses in addition to the preceding were conducted in order to shed light on these and other questions. The results are summarized in table 5.

Analysis 1 demonstrates that advance roading would be even less desirable if road construction costs were decreased by 50 percent. These somewhat surprising results can be explained by the fact that (1) both the base and accelerated road programs would be affected by lower construction costs and (2) the timing of revenues is such that when costs are reduced, the net discounted present value of the 15-mile program is increased more than that for the accelerated program.

It has been hypothesized that advance roading would be more feasible during inflation than during a period of stability. Analyses 2, 3, and 4 verify this hypothesis. Costs, revenues, and both costs and revenues were increased 3 percent, compounded annually. This rate approximates the increase in costs for Federal-aid highway construction during the 7-year period, 1962-68.[11]

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[10] A preliminary analysis has disclosed the current rate economically preferable to a slower rate of road construction.

[11] Bureau of Public Roads. Price trends for Federal-aid highway construction. U.S. Dep. Transp., Fed. Highway Admin., 2 pp., illus. 1969.

Table 5.--*Effect of changes in basic study assumptions on the economic feasibility of advance roading for management of young growth*[1/]

Analysis	Change in basic assumption								Rate of return (percent)
	Road construction costs reduced by 50 percent	All costs increased 3 percent, compounded annually	All revenues increased 3 percent, compounded annually	Residual effect of thinning included		Thinning operability limits increased to 80 percent	Rotation age reduced to 70 years	Stumpage receipts increased[3/]	
				All thinning valued at $50 per MBF	Thinning valued inversely to age[2/]				
1	X	--	--	--	--	--	--	--	-2.66
2	--	X	--	--	--	--	--	--	1.74
3	--	--	X	--	--	--	--	--	-1.04
4	--	X	X	--	--	--	--	--	1.92
5	--	--	--	X	--	--	--	--	-1.02
6	--	--	--	--	X	--	--	--	-.71
7	--	--	--	--	--	X	--	--	-1.17
8	--	--	--	--	--	--	X	--	-1.21
9	--	--	--	--	--	--	--	X	-.21
10	--	X	X	X	--	X	--	--	2.51
11	--	X	X	--	--	X	--	X	3.18

1/ Change in basic assumption indicated by (X); dash (--) indicates no change.

2/ Stumpage receipts plus an allowance for residual effects of thinning were assumed as follows: 40 years old, $65 per MBF; 50 years old, $60 per MBF; 60 years old, $55 per MBF; 70 years old, $50 MBF; 80 years old, $45 per MBF.

3/ Stumpage receipts (see table 4) for thinning yields doubled; harvest cutting tripled.

Although advance roading would appear particularly attractive during periods of inflation, such an expectation would still not warrant increasing the rate of road construction for the Tillamook Resource Area.[12/] Even with costs and revenues inflated, the rate of return for advance roading would not compare favorably with the current 5-1/2-percent guiding rates of discount used by the Department of Interior.[13/]

Analyses 5 and 6 show that the inclusion of the estimated present value of future growth response to thinning would not appreciably affect the economic feasibility of advance roading. In analysis 5, the added value would equalize all thinning values at $50 per thousand board feet. In analysis 6, stumpage plus an allowance for the residual effect of thinning would be greatest for the 40-year-old stands ($65 per MBF) and least for the 80 ($45 per MBF).

Logging equipment is being developed which may permit thinning on slopes greater than 45 percent. Analysis 7 demonstrates the economic effect of being able to thin 80 percent rather than 60 percent of thinnable age classes. The change in operability limits has only a slight positive effect upon the economic feasibility of advance roading. Likewise, reducing rotation age from 80 to 70 years (the allowable cut would increase from 34.7 million to 38.4 million board feet) would not significantly influence the economics of advance roading (analysis 8).

Stumpage values in 1967 were considerably lower than early 1969 levels. Analysis 9 shows that increasing stumpage values in line with more current market conditions enhances the economic efficiency of advance roading, but the rate of return earned is still negative. In fact, even if one could justify all the changes which have a positive effect upon the economics of advance roading--as was presumed in analyses 10 and 11--investments in advance roading would not compare favorably with current guiding rates of discount.

[12/] McKean, Roland N. Efficiency in government through systems analysis with emphasis on water resources development. 336 pp. New York: John Wiley & Sons. 1958. McKean (p. 182) objects to using inflated prices because doing so represents "...a bet on inflation...by government on its own failure to win in its struggle for stability--a type of wagering that is frowned upon in most contests."

[13/] Based on BLM Director's Information Memo No. 69-136 (unpublished), October 23, Washington, D.C. 1969. See also U.S. Congress. Interest rate guidelines for Federal decision making. Hearing before subcommittee of Joint Economic Committee, 90th Congress, January 29. 1968.

DISCUSSION OF STUDY FINDINGS

The results of this analysis are quite conclusive--accelerating the current rate of advance roading for the management of young-growth timber in the Tillamook Resource Area does not represent an attractive investment opportunity. Aside from the fact that the Federal Government must currently borrow at a higher interest rate than that earned by the most "optimistic" assessment of advance roading opportunities in the Tillamook area, the Bureau of Land Management undoubtedly has many more lucrative investment options.

In view of the cost-price relationships examined in this study, accelerating road construction would not be a profitable way to increase output from young-growth forests in the Tillamook area. The basic reason for the poor showing is that the current rate of road construction is providing considerable opportunity to thin conifer stands and accelerated road construction would not generate enough more timber to justify its cost.

APPENDIX A

PROCEDURE FOR DETERMINING ACREAGE ACCESSIBLE FOR THINNING AND HARVEST CUTTING OPERATIONS

Acreage accessible for thinning or harvest cutting operations for each of the 16 years in the investment period was calculated by use of the following equation:

$$\left[\begin{array}{c}\text{Accessible}\\ \text{acres}\\ \text{this year}\end{array}\right] = \left[\begin{array}{c}\text{Acres}\\ \text{accessible}\\ \text{end of}\\ \text{last year}\end{array}\right] + \left[\begin{array}{c}\text{Miles of}\\ \text{road built}\\ \text{this year}\end{array}\right]\left(\left\{\left[\begin{array}{c}\text{Total acres per}\\ \text{mile in tributary}\\ \text{cutting units}\end{array}\right]\right\} - \left\{\left[\begin{array}{c}\text{Acres cleared}\\ \text{per mile of}\\ \text{right-of-way}\end{array}\right]\right\}\right)$$

Note the relationship between acreage cleared for road rights-of-way and acreage accessible in a particular year for thinning and harvest cutting.

With the above equations and values from tables 1, 6, and 7, acreage in the 60-year-old, 10- to 69-percent stocking class accessible as the result of constructing 15 miles of new road during the first year of the investment period was calculated as follows:

185.71	=	165	+	15 X	[1.4948	-	0.1143]
(table 8)		(table 1)			(table 6)		(table 7)

This value as well as those for each age, type, and stocking class are shown in table 8.

Table 6.--*Distribution of total acreage of commercial forest land exposed for right-of-way, thinning, and harvest cutting operations per mile of road constructed, by phase, type, age, and stocking class*

Age	Douglas-fir stocking class			Alder (all stocking classes)
	10-69	70+		
		Thinnable	Nonthinnable	
		Phase I (First 70 miles)		
30	0.0077	1.2608	0.8406	0.6714
40	.2013	1.4677	.9785	4.7663
50	.0564	.3185	.2124	1.7051
60	1.4948	6.1798	4.1199	4.0330
70	2.4030	25.8937	17.2624	3.5359
80	0	0	22.2110	4.4118
90+	0	0	11.1142	0
		Phase II (Second 70 miles)		
30	1.0797	1.1718	.7812	1.5356
40	1.4806	2.8516	1.9011	11.5334
50	0	.0323	.0215	2.5948
60	8.5801	12.8994	8.5996	2.8661
70	14.7789	19.3116	12.8744	2.5684
80	0	0	16.4223	.4657
90+	0	0	3.3757	0
		Phase III (Last 100 miles)		
30	.0103	2.0364	1.3576	1.9371
40	.5811	2.6809	1.7873	5.7670
50	.3998	2.2219	1.4812	10.2235
60	2.6922	3.1450	2.0966	9.3567
70	1.2485	6.7611	4.5074	4.9687
80	0	0	8.3030	.6673
90+	0	0	3.7219	0

Table 7.--*Acres of commercial forest land cleared for right-of-way per mile of road constructed by type, age, stocking class, and phase of road construction*[1/]

Age[2/]	Douglas-fir stocking class			Alder (all stocking classes)
	10-69	70+[3/]		
		Thinnable	Nonthinnable	
		Phase I (First 70 miles)		
30	0	0.0964	0.0643	0
40	.0154	.1122	.0748	.2979
50	.0043	.0244	.0162	.1210
60	.1143	.4724	.3150	.3051
70	.1837	1.9796	1.3197	.2675
80	0	0	1.6980	.3372
90+	0	0	.8497	0
Total	.3177	2.6850	4.3377	1.3287
		Phase II (Second 70 miles)		
30	.0529	.0574	.0384	.0754
40	.0726	.1399	.0933	.5661
50	0	.0016	.0010	.1274
60	.4212	.6332	.4221	.1407
70	.7254	.9478	.6320	.1260
80	0	0	.8060	.0228
90+	0	0	.1656	0
Total	1.2721	1.7799	2.1584	1.0584
		Phase III (Last 100 miles)		
30	.0008	.1526	.1017	.1451
40	.0435	.2009	.1339	.4320
50	.0300	.1664	.1109	.7659
60	.2017	.2356	.1570	.7009
70	.0935	.5065	.3376	.3722
80	0	0	.6221	.0499
90+	0	0	.2788	0
Total	.3695	1.2620	1.7420	2.4660

[1/] Not included are the 10- to 20-year age classes and nonstocked forest land, because they will not produce merchantable timber during the 16-year investment period.

[2/] Acreage in 30-year-old stands does not qualify for thinning during first 10 years but will thereafter. Likewise, some 70-year-old stands will age 10 years before being accessible and/or considered for clearcutting.

[3/] The degree of slope distinguishes thinnable from nonthinnable stands. Current technology limits thinning to slopes 45 percent or less.

Table 8.--*Total acres of commercial forest land accessible for thinning and harvest cutting operations as a result of 15 miles of road constructed during first year of the investment period*[1/]

Age	Douglas-fir stocking class			Alder (all stocking classes)
	10-69	70+		
		Thinnable	Nonthinnable	
30	129.12	594.47	396.47	421.07
40	166.79	470.33	313.56	975.03
50	90.78	57.41	38.94	128.76
60	185.71	1,074.61	716.07	158.92
70	553.29	3,899.71	2,600.14	154.03
80	0	0	1,293.69	108.12
90+	0	0	748.97	0

[1/] Only a percentage of total accessible acres are thinned or harvest cut in a particular year.

APPENDIX B

YIELD TABLES FOR CLEARCUTTING AND THINNING OPERATIONS

Table 9.--*Clearcut yield table for average Douglas-fir and alder sites for Tillamook Resource Area by age and stocking class*

Age	Douglas-fir[1] stocking class		Alder[2]
	10-69	70+	
	Board feet[3] per acre		
30	3,085	13,631	1,920
40	13,664	25,146	5,200
50	23,756	35,633	8,240
60	33,358	45,092	10,880
70	42,472	53,522	13,120
80	51,097	60,924	14,240
90	--	67,298	14,720
100+	--	76,964	--

[1] Data from Bureau of Land Management, Salem District, inventory plot data for site class 160. Because of insufficient data, a yield equation could not be developed for the "10-39" stocking class.

[2] From table 13, Worthington, N. P., et al. Normal yield tables for red alder. USDA Forest Serv. Res. Pap. 36, 1960. Values shown are 80 percent of site index 70 yields. This adjustment is necessary because basic yield table is for fully stocked stands.

[3] Scribner scale to 5-inch top, 10-inch minimum d.b.h.

Table 10.--*Douglas-fir thinning yield tables for site class 160,*[1] *board feet, Scribner scale to 5-inch top, 7-inch minimum d.b.h.*

Age when thinned	Type of thinning			
	Initial		First reentry[2]	
	Nonchargeable	Chargeable	Nonchargeable	Chargeable
80-YEAR ROTATION				
40	5,485	978	--	--
50	8,653	0	6,361	978
60	10,567	0	6,689	0
70	9,916	2,070	6,160	0
80[3]	8,912	4,139	4,244	2,070
70-YEAR ROTATION				
40	4,822	1,642	0	0
50	7,867	786	5,697	1,642
60	10,567	0	5,903	786
70	9,190	2,796	6,160	0
80[3]	7,460	5,592	3,518	2,796

[1] Based on thinning guidelines developed by Tillamook project staff. Chargeable volumes (i.e., the bookkeeping adjustment expressing reduction in final harvest cutting due to thinning) were arbitrarily prorated to various thinning ages.

[2] No reentry in 40-year-old stands since younger age classes (i.e., than 40 years old) do not qualify for commercial thinning.

[3] No stands typed as 80 years at outset of investment period will be thinned. However, stands now 70 years old and not thinned during first decade will be 80 years old by the time they are thinned during the second decade.

APPENDIX C

PROCEDURE USED TO DETERMINE ACRES THINNED DURING 16-YEAR INVESTMENT PERIOD

Regardless of road plan, all qualified stands (i.e., all 40- to 70-year-old stands, 60 percent and more of normal basal area)would be thinned at least once during the 16-year investment period. But with a 10-year cutting cycle, the rate would differ as shown below:

Age at beginning of first decade	Total acres accessible for initial thinning during first decade	
	15-mile program	30-mile program
40	759	982
50	96	281
60	2,276	2,538
70	6,562	7,191

For any year, acres thinned would be one-tenth of the value shown for a particular age and road plan.

In the case of the 30-mile program, with one exception, all stands would be thinned during the first decade. Stands 30 years of age at the outset of the investment period would not qualify for thinning until the 11th year. Acres to be thinned initially during the last 6 years of the investment period are shown below:

Age at beginning of second decade	Total acres available for initial thinning during last 6 years	
	15-mile program	30-mile program
40	924	924
50	223	--
60	185	--
70	262	--
80	563	--

For both road programs, the acres of "first reentry" thinning for a particular age class for the 11th year will be the same acreage thinned initially for year 1; for year 12, the same as year 2, etc. However, acres thinned initially during the first decade will, of course, age 10 years. So a stand classified 70 years old, for example, at the time of initial thinning, would be 80 years old at the time of the first reentry thinning.

APPENDIX D

PROCEDURE FOR ALLOCATING HARVEST CUT BY AGE AND STOCKING CLASSES

To illustrate how the harvest cut is allocated to age and stocking classes, we will examine the 14th year of the 15-mile-per-year road program. Keep in mind that the oldest, and, within an age class, the lowest stocked stands are arbitrarily given first cutting priority.

First, let us consider the conifer acres accessible for logging (i.e., net of road right-of-way clearcutting and thinning) in the 80-100 age classes. Approximately 30.3 of the 34.7 million feet remain after right-of-way cutting and thinning to be allocated to these age classes:

	Conifer stocking class		
		70+	
Age	10-69	Nonthinnable	Thinnable
	- - - - - - - - - - *Acres* - - - - - - - - - -		
80	1,552.72 (3)	4,625.84 (4)	6,938.27 (5)
90	0	115.21 (2)	0
100		51.65 (1)	

The numbers in parentheses indicate cutting priorities. Following this order, volume accessible for harvest cutting was determined by multiplying acres accessible by corresponding values in table 9 (i.e., per-acre volumes):

		Board feet
1. Volume to be allocated	=	30,263,008
2. Volume accessible in 100-year-old class 76,964 x 51.65	=	-3,974,921
3. Volume to be allocated (1-2=3)		26,288,087
4. Volume accessible in 90-year-old class 67,298 x 115.21	=	-7,753,638
5. Volume to be allocated (3-4=5)	=	18,534,449

Similarly, the remaining volume was allocated to the 80-year-old age class. Table 11 shows how not only the "allowable" conifer harvest cut was allocated by age and stocking classes, but also the road right-of-way cut. In addition, the allocation of the 1.5 million-board-foot hardwood allowable cut is shown.

Table 11.--*Allocation of conifer and hardwood allowable cuts to harvest and road right-of-way cuttings, by age and stocking class*

Age	Type of cut[1/]	Conifer stocking class			Hardwoods
		10-69	70+		
			Thinnable	Nonthinnable	
		- - Board feet, Scribner scale, to 5-inch top - -			
30	H	0	0	0	0
	R	0	0	0	0
40	H	0	0	0	0
	R	164	57,559	38,360	11,318
50	H	0	0	0	0
	R	15,501	107,380	71,569	53,395
60	H	0	0	0	0
	R	15,011	112,550	75,011	124,995
70	H	0	0	0	0
	R	128,499	189,147	126,044	137,937
80	H	18,534,510	0	0	945,423
	R	71,664	462,870	308,519	79,502
90	H	0	0	7,753,638	136,405
	R	0	0	627,991	11,025
100+	H	0	0	3,974,921	0
	R	0	0	321,863	0

[1/] H = Harvest cut.
R = Road right-of-way cut.

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Two Keys for Appraising Forest Fire Fuels

George R. Fahnestock

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Introduction

This is an attempt to characterize forest fire fuels[1] in a new way. The immediate purpose is to provide means for recognizing and tentatively evaluating, in the field, the fire spread potential and the crowning potential of fuels on the basis of readily observed characteristics without need for prior technical knowledge of vegetation or experience with fire. The medium employed is the dichotomous key, familiar to natural scientists; this is supplemented by a vocabulary of newly defined terms for describing fuel characteristics. The ultimate goal is to establish the framework for a permanent, universal fuel appraisal system.

Forest fire fuels comprise an infinitely varying conglomeration of living and dead vegetation. Numerous existing systems characterize this material, or some parts of it, in terms of taxonomic identity, ecological significance, and economic value. Each type of characterization implies something about the vegetation as fuel, but none provides a complete fuel evaluation. Therefore, foresters have devised their own schemes for evaluating, or "classifying," fuels in terms that have meaning for fire control.

Fuel classification in the United States is based on a system developed 30-odd years ago before any information existed on specific relations between measured fuel characteristics and fire behavior (Hornby 1936).[2] The unit of measurement is fuel type, a largely impressionistic integration of vegetation and site factors into dual ratings for expected rate of fire spread ("rate of spread") and difficulty of effecting control ("resistance to control"). Regional variations of the system provide photographic manuals for identifying fuel types, and most give numerical values for rate of spread and resistance to control.[3] The value scales are regional, without a common base.

Long use attests to the great practical value of the present fuel classification system in fire control planning and, to a lesser degree, in fire suppression. However, increasing dissatisfaction suggests that the system's longevity owes much to the difficulty of developing a suitable replacement. Departures from the general scheme thus far have dealt with rather narrow, usually local or regional problems, e.g., the first known fuel key, relating "blowup potential" to total weight (Wendel, Storey, and Byram 1962). To be a real improvement, a comprehensive new approach must (1) be based on objective measurement of specific fuel characteristics, (2) be much more flexible and versatile than the present system, and (3) use a universal rating scale.

Keys such as those commonly used to identify natural substances and organisms afford a versatile and flexible approach to fuel characterization. In principle, such keys distinguish between significant conditions by means of progressive subdivision, using as the criterion at each division point a characteristic that one entity possesses and all others do not. Thus the job of distinguishing between two complex fuels is reduced to a series of rather minor decisions, each of which can be made on the basis of objective observation or measurement. If the right basic attributes are used for characterization, critical levels can be redefined, outputs can be recalculated, combinations can be added, and keys can be combined or separated to incorporate new knowledge without invalidating the system.

[1] *Includes grassland, brush, woodland, forest, and tundra fuels.*

[2] *Names and dates in parentheses refer to Literature Cited, page 23.*

[3] *All regions use at least four relative levels: "Low," "Medium" or "Moderate," "High," and "Extreme." Forest Service Regions 1 and 4 add a "Flash" rate-of-spread category for grass and some other fine fuels. Fuel types are designated as "Low-Low (L-L)," "High-Extreme (H-E)," etc., with rate of spread always the first element.*

Fuel Terminology

An effective descriptive system must have a vocabulary of precisely defined terms. In the case of fuels, the terms must describe size, quantity, and arrangement of particles, the intrinsic characteristics that govern fire behavior and impede fire suppression (Fons 1946, Fahnestock 1960, Anderson et al. 1964, Rothermel and Anderson 1966). The available terminology for characterizing fuels is notably meager, and the same words are commonly used to mean entirely different things; e.g., "heavy" for either coarse or abundant, and "light" for either fine or sparse. "Heavy" and "light" are used also to describe weather phenomena, strength of attack, and other factors in fire control; consequently, their meanings in each context often are vague to the point of uselessness.

The proposed keys use criteria of size, quantity, and arrangement that can be defined by rather simple observations. The suggested terminology, which is completely new, defines these attributes in quantitative terms to the extent currently possible. Some dimensions are based on fire behavior theory and drying regimes to be used in the National Fire-Danger Rating System, but many, at this stage, represent mainly experienced judgment.

The terms are grouped into four categories: size and shape of particles, compactness, vertical position, and horizontal continuity;[4] i.e., size and three aspects of arrangement. Figures 1-4 illustrate different combinations of these characteristics. These attributes can be expressed in terms of simple, easily estimated dimensions and distances. However, quantity, usually expressed as weight per unit of land area, is extremely difficult to estimate. Therefore, levels of quantity are not defined specifically for use in the keys but are inferred as functions of size and arrangement. Certain other variables and interactions are ignored for the present because their effects on fire behavior are understood poorly, if at all; these include density (specific gravity), chemical composition, and the intermixing of particles of different sizes and moisture contents (e.g., green and dead). As knowledge improves, correction, refinement, addition, and deletion should be possible without reducing the overall usefulness of the terminology.

[4] *Terms for horizontal continuity are used to interpret areal groupings of key readouts, not in the keys themselves.*

Size and Shape of Particles

Tinder — low-density, commonly amorphous solids or aggregates of particles; includes duff, peat, rotten wood.

Fine — thin (<one-thirty-second inch) or of small diameter (<one-eighth inch); equivalent to 1-hour-timelag category used in fire-danger rating (cf. USDA Forest Service 1956); includes leaves, grass, fine twigs, moss.

Small — minimum dimension, one-eighth inch; maximum cross-sectional area, 0.2 square inch (equivalent to ½-inch-diameter cylinder); approximately equivalent to 10-hour-timelag category used in fire-danger rating; includes woody stems, branches, and slivers, and thin sheets of bark.

Medium — minimum dimension, one-half inch; maximum cross-sectional area, 7 square inches (equivalent to 3-inch cylinder); approximately equivalent to 100-hour-timelag category used in fire-danger rating; includes branches, stems, and slivers, and bark.

Coarse — minimum dimension, 3 inches; maximum cross-sectional area, 113 square inches (equivalent to 12-inch cylinder); timelag, >100 hours; includes saplings, poles, logs and chunks, slivers, and bark.

Big — minimum dimension, 12 inches; timelag much more than 100 hours; includes all material not covered above.

Compactness

Fuels in the surface layer:

Compact — particles in close contact with each other over much of their surfaces; voids in fuel bed almost imperceptible — examples are beds of conifer needles ≤1½ inches long, matted hardwood leaves, and other compacted fine fuels; applies mainly to fine size class.[5]

Thatched — particles oriented horizontally in close juxtaposition, touching each other at many points; voids perceptible in fuel bed but less conspicuous than fuel particles; examples are beds of conifer needles 1½ to 6 inches long, unmatted small hardwood leaves (willow, birch, black gum, beech, elm), twigs; also longer needles and larger leaves, after compaction by snow or winter rain or when quantity is too small for next category; applies to fine and small size classes.

Jumbled — particles variously oriented in close association, touching and supporting each other at several to many points; voids in fuel bed conspicuous, having volume many times greater than fuel particles; examples are conifer needles >6 inches long, unmatted large hardwood leaves, and concentrations of woody fuel; applies to fuels of all sizes.

Fluffy — particles generally self-supporting, oriented approximately in normal growing position; fuel bed has appearance of space with suspended particles; examples are grass, ferns, lichens, moss; applies to fine size class only.

Fuels above the surface layer:

Dense — particles mostly <3 inches apart within each integral group (spray, branch); groups no farther apart than 12 inches horizontally and 18 inches vertically; applies to only fine and, occasionally, small fuels. Examples are logging slash with foliage attached and much-branching, small-leaved brush.

Open — particles 3 to 6 inches apart within groups; groups 12 to 18 inches apart horizontally and 1½ to 3 feet vertically. Examples are logging slash of fine-twigged species after foliage falls and less-branched brush.

Fuels in all positions:

Sparse — too little fuel present to produce any of the conditions defined above.

[5] *"Tinder" fuels may be considered compact by definition.*

Vertical Position

Subsurface — beneath all other fuel with no exposure to the atmosphere. Consists mainly of partially decomposed material in the tinder and fine size classes; sound larger components may be imbedded. May be absent.

Surface — stratum not more than 1 foot deep resting on mineral soil or subsurface fuel, with its top exposed to the atmosphere. Includes litter, larger debris, and associated low-growing vegetation.

Low — lowest, essentially homogeneous, completely aerial stratum; mean depth (height) usually <6 feet.

Intermediate — homogeneous stratum immediately above low stratum and usually reaching ≤ 15 to 20 feet in average height.

Subcanopy — stratum between intermediate and canopy; considered to be absent if base of canopy is within 10 feet of intermediate or lower stratum.

Canopy — stratum containing crowns of tallest vegetation (living and/or dead) >20 feet high.

Ladder — providing vertical continuity between strata, but horizontal continuity too poor to be considered a fuel bed.

Horizontal Continuity

Uniform — essentially the same fuel bed over entire area;[6] breaks and patches of different fuel few (as defined by key), generally narrower than (1) the expanse of typical fuel between them and (2) twice the maximum height of available fine fuels; breaks (without fuel, as defined above aggregating less than 25 percent of area.

Mixed — containing up to 50 percent of different fuel distributed in patches no wider than twice the average height of finest fuels in the taller fuel type.

Interspersed — containing up to 50 percent of a different fuel or fuels distributed in patches wider than twice the average height of finest fuels in the taller fuel type but not large enought to be rated or mapped separately.

Broken — 25 to 75 percent of the area occupied by breaks wider than the expanse of fuel between them and wider than twice the maximum height of finest fuels, but not wider than five times the maximum height of finest fuels.

Interrupted — containing one or more breaks wider than five times the maximum height of fine fuels and long enough to be of significant assistance in fire suppression.

[6] *Size or limits of area to be defined by map or description for each specific situation.*

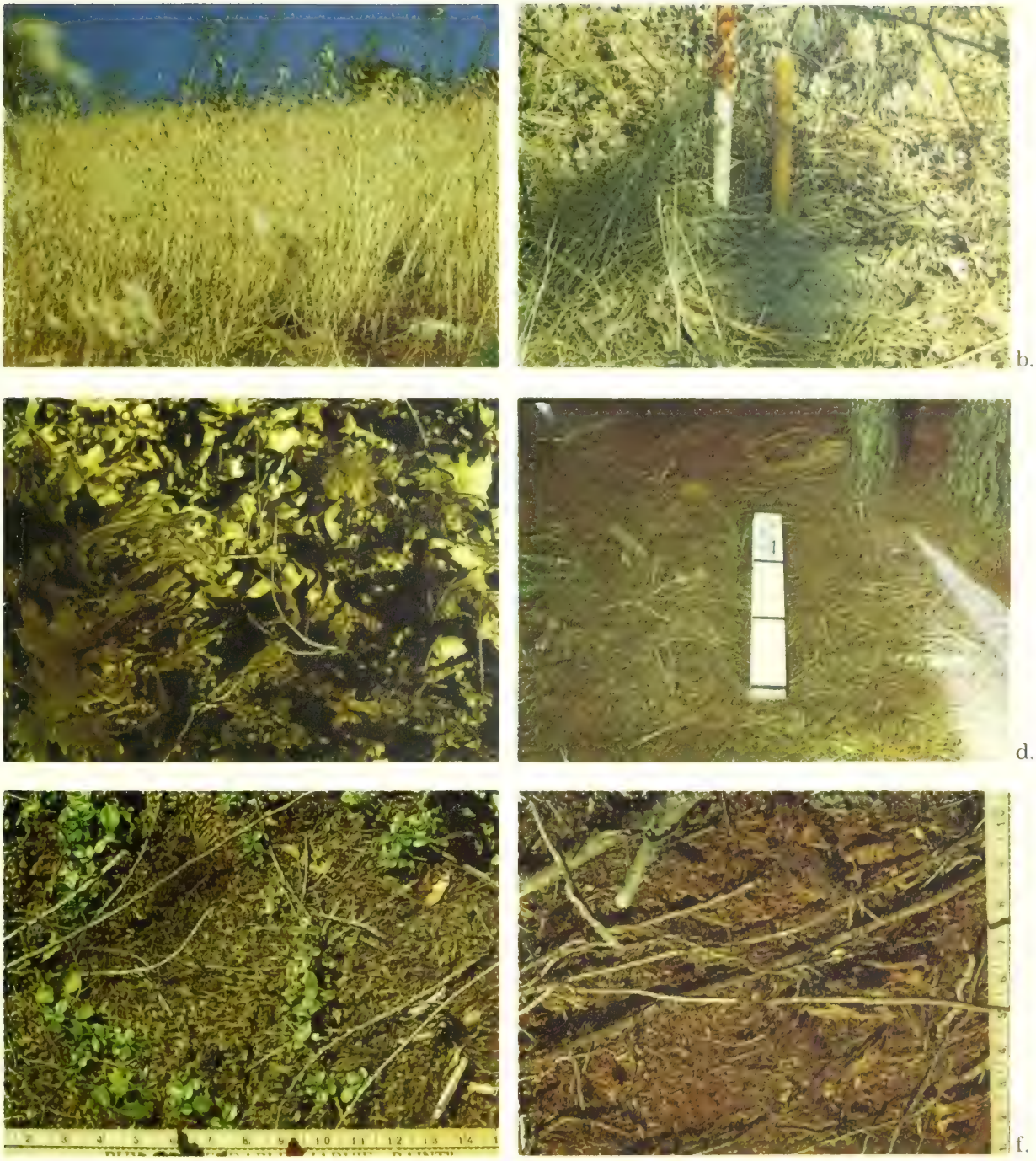


Figure 1. — Fine surface fuels.

a. Fluffy — cheatgrass (*Bromus tectorum* L.), Montana.
b. Jumbled to fluffy — longleaf pine litter (*Pinus palustris* L.), Louisiana.
c. Jumbled — hardwood leaves, California.
d. Thatched — loblolly pine (*P. taeda* L.), North Carolina.
e. Compact — western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), Washington.
f. Tinder — rotten wood, Washington.

Figure 2. — Larger fuels (all Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) and western hemlock, Washington).
a. Small b. Medium c. Coarse d. Big

a.

b.

c.

d.

f.

e.

Figure 3. — Various conformations of low and intermediate fuels.

a. Low: fine and small, dense to open; over surface: fine — old chamise (*Adenostoma fasciculatum* H. & A.), California.

b. Low and intermediate: fine and small, dense; over surface: fine sparse — chamise, California.

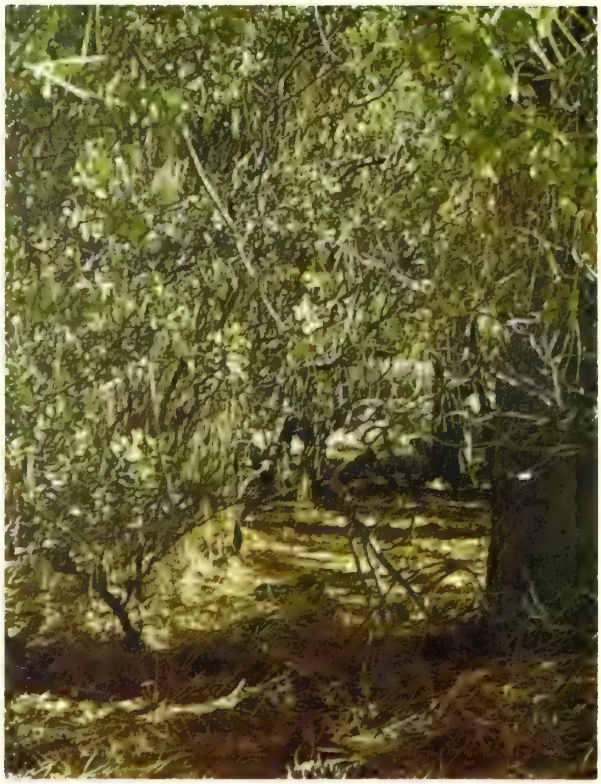
c. Low: fine, dense; over surface: fine, jumbled — lambkill (sheep laurel) (*Kalmia angustifolia* L.), New Jersey.

d. Low and intermediate: fine to coarse, dense to open — lodgepole pine slash (*Pinus contorta* Dougl.), Oregon.

e. Low and intermediate: fine and small, dense — canebrake (*Arundinaria* spp.), North Carolina.

f. Intermediate: fine, dense; over surface: fine, thatched or compact — swamp cyrilla or titi (*Cyrilla racemiflora* L.), Florida.

a.



b.

c.

d.

Figure 4. — Ladder fuels.

a. Loose bark on redshank chamise (*Adenostoma sparsifolium* Torr.), California.
b. Draped pine needles, California.
c. Scaly bark, dead twigs, and lichens on black spruce (*Picea mariana* (Mill.) B.S.P.), Alaska.
d. Beard lichens (*Usnea* sp.), Washington.

Mechanics of the Keys

Both keys — rate of spread and crowning potential — employ the basic rationale and mechanics of the dichotomous key. The user proceeds, step by step, through a series of yes/no choices, to a combination of conditions that defines the fuel in question. Procedure for using the keys is:

1. Enter key with "A."

2. If condition defined by "A" fits fuel under observation, proceed to "B" as directed.

3. If "A" does not fit, proceed to "AA" and on to "AAA" if necessary.

4. Proceed through the alphabet in the same manner to the key readout that has a type number (XX) and a rating rather than an instruction to proceed further.

The fuel keys are not strictly dichotomous in form, since some steps require choice among three or four mutually exclusive conditions. However, these situations are merely shortcuts used to reduce the number of steps that would be required to preserve pure dichotomy.

A second minor departure from the typical eliminative process is that some portions of the fuel keys are accumulative. Therefore degree or progress through a key does not represent relative rating of the fuel.

Both keys have been repeated on tearsheets at the end of the report.

Rate-of-Spread Key

Key No. 1 defines 36 distinct combinations of fuel characteristics in terms of potential rate of fire spread. Fine fuels are considered to control spread so long as they are not characterized as "sparse" or absent. Fire spread is assumed to be entirely through the fuel bed itself, governed by thermal radiation, convection, and conduction within the bed. No basis exists for estimating the expected number and characteristics of firebrands for mass transport, and consequent spread by spotting, that any fuel will produce.

The key does not take into consideration the influences of topography or weather, either synoptic or as modified by terrain and vegetation. These are considered external factors whose effects can be combined mathematically with the effect of fuel characteristics to calculate expected rate of spread in any given situation. The basis for estimating effects of external factors is available in several forms — publications (e.g., Barrows 1951, Geiger 1966, USDA Forest Service 1964), the proceedings of national fire behavior courses, and regional fire control handbooks.

A recognized weakness of the key is lack of any distinction between living and dead vegetation. Dead material is everywhere the basic fuel whose flammability depends only on weather. However, nearly every vegetative region has species that burn while living as a result of basic chemical composition, physiological changes, and drought (Philpot 1968, 1969). In some regions, e.g., southern California, living vegetation is the most important fuel. To use the key in such areas, one must recognize, on the basis of local knowledge, and consider as available fuel the living vegetation that is currently flammable. Nonflammable living vegetation is regarded as so much empty space, since its effect on fire spread is not known.

Readouts of the key are relative ratings on a scale of 100 conditioned by the following assumptions:

1. No wind
2. Other external factors equal (aspect, slope, stand density, etc.)
3. No change in relative rate of spread with change in fire danger[7]
4. Finest fuel present in appreciable quantity controls spread, although loading of coarser fuel may be greater.

Assumption 3 is not strictly true, but it provides a premise from which to qualify and take exception (see "Interpretation of Ratings").

As the basis for ratings, linear rates of spread for a wide range of essentially homogeneous surface fuels were calculated at the Northern Forest Fire Laboratory, by means of a mathematical model[8] (table 1). The mean rate of spread for two common grass types was given the top rating of 100; field experience strongly suggested that the actual difference between broomsedge (*Andropogon*

[7] *Used loosely here to mean the summation of effects of all weather factors that affect fire behavior.*

[8] *Rothermel, R. C. The effects of fuels on fire intensity and rate of spread. (Unpublished paper presented at the Forest Fuels Work Conference, Northern Forest Fire Laboratory, Missoula, Mont., March 3-6, 1969.)*

Table 1. — Assumed inputs and calculated rates of spread for fine, homogeneous fuels

Fuel, by compactness class	Heat value	Mineral content		Density	Surface/ vol. ratio	Loading	Depth	Fire spread	
		Total	Effect					Rate	Rating
	B.t.u./lb.	Percent dry wt.		Lb./ft.^{3}	Ft.^{2}/ft.^{3}	Lb./ft.^{2}	Ft.	Ft./min.	
Fluffy:									
Broomsedge	7,350	5.27	1.04	21.2	2,440	0.15	3.0	9.40	–
Cheatgrass	7,350	5.27	1.04	21.2	4,390	.02	1.0	5.58	–
Mean for grasses								7.49	100
Jumbled:									
Longleaf pine litter	8,744	3.87	1.55	31.8	1,750	.14	.40	1.38	18
do.	8,744	3.87	1.55	31.8	1,750	.07	.12	.43	6
Thatched:									
Ponderosa pine litter	8,744	3.87	1.55	31.8	1,750	.14	.10	.30	4
do.	8,744	3.87	1.55	31.8	1,750	.07	.07	.23	3
Western white pine litter	8,456	3.34	2.54	33.5	2,800	.14	.09	.29	4
do.	8,456	3.34	2.55	33.5	2,800	.07	.05	.17	2
Compact:									
Douglas-fir litter	8,500	4.09	2.45	32.0	2,160	.14	.04	.05	1
do.	8,500	4.09	2.45	32.0	2,160	.07	.02	.02	<1

virginicus L.) and cheatgrass is much less than the calculated difference, possibly nonexistent. Maximum rate of spread in each other category was divided by the mean for grass to obtain the other relative ratings. Maxima were used to avoid underestimation; the assumed inputs on which they were based were not absolute maxima.

Ratings for the more complex fuels were extrapolated from the few basic determinations on the basis of judgment guided by the size and spacing relations developed by Fons (1946) and a few calculations with a rate-of-spread model for heterogeneous fuels. The calculations indicated potential spread in heavy logging slash and chaparral approximating that in grass and suggested about a 90-percent reduction in slash when the needles fall off.

Sampling units for rating fuels with the key must be randomly or mechanically selected small plots. One milacre appears to be a reasonable, all-purpose size. A larger plot usually contains so much variation that giving it a single rating is impossible; a much smaller plot too often is virtually devoid of fuel or contains only surface fuel. Considerable variation may occur even on a single milacre; therefore, the practice should be to key out the fuel that gives the highest rating and from which fire could spread outside the plot. This judgment admittedly is somewhat subjective, but anybody who has had a bonfire can be reasonably sure of judging correctly on such small plots. More use of the keys will be needed to determine the number of observations needed. Ten plots appear to give a reasonable mean rate-of-spread rating for most areas; more are needed in patchy fuels.

Key No. 1: Rate of Spread

	Rating
A. Fuel essentially confined to surface layer — B	
B. Fine fuel present, not sparse — C	
C. Fine fuel fluffy (1) (fig. 1a, b)	100
CC. Fine fuel jumbled (2) (fig. 1b, c)	18
CCC. Fine fuel thatched — D	
D. Small fuel jumbled (3)	10
DD. Small fuel, if present, not jumbled (4) (fig. 1d)	5
CCCC. Fine fuel compact — E	
E. Small fuel jumbled (5) (fig. 2a)	5
EE. Small fuel thatched (6)	3
EEE. Small fuel sparse or absent — F	
F. Medium fuel jumbled (7) (fig. 2b)	3
FF. Medium fuel not jumbled (8) (fig. 1e)	1
BB. Fine fuel sparse or absent — G	
G. Small fuel jumbled or thatched (9)	3
GG. Small fuel sparse or absent — H	
H. Medium fuel jumbled (10)	2
HH. Medium fuel not jumbled — I	
I. Larger fuel jumbled (11)	1
II. Larger fuel not jumbled (12)	<1
AA. Fuel available in low and/or intermediate layers — J	
J. Low dense or open; intermediate fuel sparse or absent — K	
K. Fine low fuel dense to open — L	
L. Fine low fuel dense — M	
M. Surface fuel present, not sparse — N	
N. Surface fuel fine and/or small (13) (fig. 3a, c)	100
NN. Surface fuel medium and larger (14)	80
MM. Surface fuel sparse or absent (15) (fig. 3b)	65
LL. Fine low fuel open — O	
O. Surface fuel present, not sparse — P	
P. Surface fuel fine and/or small — Q	
Q. Surface fuel fluffy (16)	100
QQ. Surface fuel jumbled or thatched (17)	75
QQQ. Surface fuel compact (18)	50

	Rating
PP. Surface fuel medium and larger (19)	40
OO. Surface fuel sparse or absent (20)	30
KK. Fine low fuel sparse or absent — R	
R. Small low fuel dense — S	
S. Surface fuel present, not sparse — T	
T. Surface fuel fine and/or small — U	
U. Surface fuel fluffy (21)	100
UU. Surface fuel jumbled or thatched (22)	50
UUU. Surface fuel compact (23)	30
TT. Surface fuel medium or larger (24)	30
SS. Surface fuel sparse or absent (25)	20
RR. Small low fuel not dense — A	
JJ. Low fuel and fine and small intermediate fuel dense or open — V	
V. Low fuel fine and/or small — W	
W. Surface fuel present, not sparse — X	
X. Surface fuel fine and/or small (26) (fig. 3d, e)	100
XX. Surface fuel medium and larger (27)	90
WW. Surface fuel sparse or absent (28) (fig. 3f)	70
VV. Low fuel medium and larger — Y	
Y. Surface fuel present, not sparse — Z	
Z. Surface fuel fine and/or small — a	
a. Surface fuel fluffy or jumbled (29)	100
aa. Surface fuel thatched or compact (30)	80
ZZ. Surface fuel medium and larger (31)	65
YY. Surface fuel sparse or absent (32)	50
JJJ. Low fuel sparse or absent; fine and small intermediate fuel plentiful — b	
b. Ladder fuels present — c	
c. Fine and/or small surface fuels present, not sparse — d	
d. Surface fuel fluffy or jumbled (33)	100
dd. Surface fuel thatched or compact (34) (fig. 4a)	80
cc. Fine and/or small surface fuel sparse or absent — e	
e. Medium and larger surface fuels jumbled (35)	60
ee. Medium and larger surface fuels not jumbled (36)	40
bb. Ladder fuels absent — A	

Interpretation of Ratings

Horizontal continuity must be considered in evaluating natural fuel beds as to rate of spread. The terms defined earlier can be used to interpret, or correct, mean ratings obtained from sample plots. Such interpretation is especially important where patches of high-hazard fuels are interspersed with low-hazard patches or blanks larger than a sample plot. Until research defines significant levels of continuity and measures their effects, the following rules of thumb (not yet field tested) are suggested for calculating area means:

Continuous. — Use mean of highest rated 50 percent of fuel-occupied plots, disregarding blanks.

Mixed. — Use mean of highest rated 75 percent of occupied plots, disregarding blanks.

Interspersed. — Use mean of all occupied plots, disregarding blanks.

Broken. — Use mean of all plots, including blanks.

Interrupted. — Use one-half the combined means of fuel beds separated by breaks.

The 100-point scale implies a degree of accuracy in rating fuels that does not now exist. The old regional fuel classification schemes defined five rate-of-spread classes at most; ability to discriminate and evaluate many more has not been proven. However, the ultimate goal is to be able to estimate actual rate of spread, which can exceed 100 chains of perimeter an hour. Therefore, retention of the 100-point relative scale appears logical. Differences smaller than five points in the present ratings, and perhaps some larger ones, cannot be considered significant. However, they are thought to be in the right direction, and research may show that they are real.

The ratings represent relative potential rates of spread, which would be used in fire control planning. These are most reliable under severe burning conditions. Knowledge of present and past weather must be used to interpret ratings for current use, as in scouting a fire. Fuels clearly dominated by fine, dead, well-aerated components have high ratings, but they burn slowly or not at all during periods of high humidity or after even light rain, regardless of buildup. On the other hand, types largely made up of coarse fuels have much lower ratings but continue to support fire spread under temporarily damp conditions if buildup is high. And types with high ratings whose major component is living vegetation commonly require both high buildup and dry current conditions to burn at all. Thus there is no such thing as a static, self-sufficient fuel rating.

Crowning Key

Key No. 2 identifies fuel characteristics that lead to crown fires in the canopy and subcanopy,[9] according to the accepted definition of crowning, i.e., "Fire advancing from crown to crown . . ." (USDA Forest Service 1956).[10] The key ranks crowning potential by increasing numbers from 0 to 10. The rankings are based on observations and deductions by the author and are purely ordinal. No technique is available for calculating the mathematical probability that a fire will crown under given conditions.

The crowning key covers fire propagation both by progression of a flame front and by mass transport of firebrands (spotting). Both types of propagation operate when fine aerial fuels are abundant. Mass transport becomes increasingly important as amount and continuity of aerial fuels decline, and it is the only aerial mechanism of spread when crowns are dead, leafless, and noncontiguous. Wind or upslope is necessary for continuous spread through the crowns to occur. Factors conducive to rapid spread and high intensity of fire in lower fuels — e.g., drought, large accumulations of fuel — also abet crowning but are not prerequisite to it. Therefore, the key is based only on essential attributes of the crowns themselves (fig. 5); the user must consider the other factors to estimate whether crowning is likely to occur in any given situation.

[9] *Fires are also commonly said to "crown" through brush of no great height; the rate-of-spread key implicitly covers this type of spread.*

[10] *"Crowning-outs," "torch-outs," or "flareups" of individual trees or clumps do not qualify as crowning under this definition. These phenomena contribute significantly to rate of fire spread and difficulty of control by scattering many embers but do not, of themselves, constitute spread through the crowns.*

Figure 5. — Crown fuels.

a. Dense live crown — Engelmann spruce (*Picea engelmannii* Parry), Idaho
b. Open live crown — longleaf pine, Louisiana
c. Dead crowns — slash pine (*Pinus elliottii* Engelm.), Mississippi
d. Snags spaced closer than 33 feet — Douglas-fir, Oregon

Key No. 2: Crowning Potential

	Rating
A. Foliage present, trees living or dead — B	
B. Foliage living — C	
C. Leaves deciduous or, if evergreen, usually soft, pliant, and moist; never oily, waxy, or resinous (1)	[a]0
CC. Leaves evergreen, not as above — D	
D. Foliage resinous, waxy, or oily — E	
E. Crowns dense — F	
F. Ladder fuels plentiful — G	
G. Canopy closure >75 percent (2)	9
GG. Canopy closure less (3)	7
FF. Ladder fuels sparse or absent — H	
H. Canopy closure >75 percent (4)	7
HH. Canopy closure less (5)	5
EE. Crowns open — I	
I. Ladder fuel plentiful (6)	4
II. Ladder fuels sparse or absent (7)	2
DD. Foliage not resinous, waxy, or oily — J	
J. Crowns dense — K	
K. Ladder fuels plentiful — L	
L. Canopy closure >75 percent (8)	7
LL. Canopy closure less (9)	4
KK. Ladder fuels sparse or absent — M	
M. Canopy closure >75 percent (10)	5
MM. Canopy closure less (11)	3
JJ. Crowns open — N	
N. Ladder fuels plentiful (12)	3
NN. Ladder fuels sparse or absent (13)	1
BB. Foliage dead — O	
O. Crowns dense — P	
P. Ladder fuels plentiful — Q	
Q. Canopy closure >75 percent (14)	10
QQ. Canopy closure less (15)	9
PP. Ladder fuels sparse or absent — R	

[a] *Rare instances have been reported, resulting from extreme drought.*

	Rating
R. Canopy closure >75 percent (16)	8
RR. Canopy closure less (17)	4
OO. Crowns open — S	
S. Ladder fuels plentiful (18)	6
SS. Ladder fuels sparse or absent (19)	2
AA. Foliage absent, trees dead — T	
T. Average distance between trees 33 feet or less — U	
U. Ladder fuels plentiful — V	
V. Trees with shaggy bark and/or abundant tinder (20)	10
VV. Trees not as above (21)	8
UU. Ladder fuels sparse or absent — W	
W. Trees with shaggy bark and/or abundant tinder (22)	10
WW. Trees not as above (23)	5
TT. Average distance between trees >33 feet (24)	2

Field Test of Keys

Preliminary versions of the keys were field tested in Florida, North Carolina, Minnesota, Montana, California, and Washington to assay their usefulness and the reactions of potential users. Tests in the first five locations included comparisons of ratings of the same points by two or more people. Duplicate tests were not made in California and Washington where experienced fire research personnel concentrated on comparing the key ratings with their experience in regional fuel types. Both the objective and subjective results of testing pertain to the rate-of-spread key almost exclusively because crowning potential was negligible on most of the test areas.

Consistency of Determinations

Fewer actual field determinations were made than had been hoped for, and they were made in diverse ways. Nevertheless, consistency among users of the key was remarkably good, as measured by comparison of type numbers arrived at and of mean ratings for areas.

Eight men with diverse backgrounds at the Northern Forest Fire Laboratory tested the rate-of-spread key in a mixed conifer stand (mainly Douglas-fir, western larch (*Larix occidentalis* Nutt.), and Engelmann spruce) near Missoula, Mont. Emphasis was mainly on analyzing the construction and operation of the key, but members of the group did rate the same seven points independently. Agreement on type number readout ranged from two of seven[11] to six of eight. However, all four experienced fire researchers agreed on two types, and three of the four on two others;

[11] *Three individual ratings were omitted, one by each of three testers.*

the spread was only 8 points, 49 to 57. The extreme range of mean ratings was from 40 for a forestry student to 76 for a visiting engineering professor.

Personnel of the Southern Forest Fire Laboratory rated 12 points in Florida and 13 in North Carolina, usually only one point in a type. In Florida all three men agreed on four types and two of three on four more. Averaging of ratings has little meaning under the circumstances, but, for what it is worth, the spread from high to low average was 11 points (78 to 67). Two of the same men made the North Carolina ratings, agreed on 11 out of 12, and had mean ratings only four points apart (71 and 67).

Two seasonal employees of the North Central Forest Experiment Station rated 12 points in an area of jack pine slash. They agreed on 10 of 12 points, and their averages were only one point apart (43 and 42).

In a test of the crowning key the two North Carolina observers agreed on all eight points that both rated. In Florida all three observers agreed on four of the six points rated, and two of three agreed on the other two points. Except at these points, fuels above the intermediate stratum were either lacking or so sparse that crowning potential was not considered worth rating.

Accuracy of Ratings

Fuel ratings made with the preliminary rate-of-spread key did not accord particularly well with regional fuel-type standards. The most important discrepancy resulted from failure to recognize the rapid spread in grass, which is in the highest rate-of-spread type in every region of the country. The revised key put grass in about its proper relative position by adding the "fluffy" compactness class. At the opposite extreme, the key gave high ratings to all southern brush types because green foliage and twigs were counted as fuel. Some of these types on the wettest sites seldom burn, hence are "Low" in the regional scale. However, all can burn fast and hot after sufficient drought. Mature pine timber in California was overrated because (1) "thatched" litter was interpreted as "jumbled" at one point, and (2) the other point was in the worst combination of surface and low fuels on the area. These test results emphasize that knowledge of the readiness of green vegetation to burn is prerequisite to use of the keys, that definitions must be clearly understood, and that a fuel evaluation by any means at a single point is not adequate to characterize an area.

Actually, close agreement with regional ratings would not necessarily be a point in favor of the key. As stated earlier, the old ratings include allowances for slope steepness, topographic exposure to weather, and effects of stand characteristics on microclimate, whereas the key attempts to deal strictly with properties of the fuels themselves. Also the absolute and relative values of ratings vary strikingly among regions. Comparison of northern Rocky Mountain with Pacific Northwest fuel types gives an example of interregional disparity of ratings for fuels that are similar appearing. The absolute ratings for the northern Rocky Mountains in chains-per-hour are Low-3.5, Medium-6.0, High-13.0, Extreme-20.0; on a 100-point relative scale these would become 17.5, 30, 65, and 100. Reduced to a 100-point scale, the corresponding Pacific Northwest values would be 1, 4, 20, and 100. In another comparison, rate of spread in southeastern fuels generally is much higher for a given descriptive word rating than in western fuels. The predominance of fine, well-aerated fuels in open forest stands in the South is responsible.

Several pointed out that inability to account for continuity prejudiced the ratings of areas even though individual points were rated accurately. Thus, mean slash ratings, especially for jack pine, appeared low; and the range in point ratings showed why — bodies of extreme-spread fuels alternated with areas that could be completely devoid of fuel. Fire, especially when wind driven, readily jumps considerable gaps in otherwise high-rated fuels, but knowledge is not available to evaluate discontinuities. This criticism led to the suggestion that continuity be used in deriving mean ratings.

There was no basis for evaluating the accuracy of the key to crowning potential, since this factor is not rated separately by existing fuel-type systems and has never been measured objectively.

User Reaction

All who tested the keys reacted favorably to the concept involved, and they raised surprisingly few questions concerning the ratings. However, all made suggestions for improvement, and most raised questions about the validity and adequacy of various aspects of construction and use. Even after revisions, there are still areas of continuing dissatisfaction:

1. *Terminology and definitions.* — The suggested terminology is not fully satisfactory, as a full complement of terms and precise definitions must evolve over time. The most serious flaw is the absence of terms by which to define loading with some precision as a discrete variable. Unfortunately, simple criteria of loading that can be applied universally are not available. There also is no provision for recognizing chemical differences; perhaps local adaptations of the keys can fill the need temporarily by "plugging in" species and physiological condition — e.g., stage of development — when their effects on flammability are known.

2. *Number of fuel combinations to be rated.* — One reviewer felt the rate-of-spread key should cover all possible combinations of fuel characteristics; others advocated reducing the number of combinations by merging or eliminating some with nearly equal ratings. The principle finally followed was to provide a basis for (1) distinguishing between fuels that look somewhat alike but burn quite differently and (2) showing that some fuels that superficially look quite different result in essentially the same fire behavior.

3. *Confidence in identifying and rating fuel types.* — Everybody testing the keys felt some uncertainty about the path he followed through them and the accuracy of the readouts at which he arrived. Some uncertainty in the use of fuel keys, which are a new development, should not dismay anybody who has taken his lumps in using the much more precise taxonomic keys that are accepted as valuable tools for identifying plants, animals, rocks, etc. Identification of fuel types cannot be precise because the criteria and supporting terms are not defined precisely. Therefore, the path through the key depends partly on the judgment of the person using it. Deciding between criteria of compactness is particularly vexing; "thatched" grades into "jumbled," "dense" into "open," and so on. Consequently, one is seldom sure he has followed the "right" path and arrived at the best characterization of the fuel; in fact, men experienced in rating fuels frequently can tell that they have obtained an inaccurate rating and should start over. (Possibly too much knowledge biases judgment, especially when it becomes obvious that the key is going to rate a point much higher or lower than the obvious general level for an area.) However, the same problem would exist if the criteria were precise measurements. The characteristics of fuel are continuous variables, mostly within wide ranges, and their effects on fire behavior are also continuous. Therefore, breaks in the continuous scale, which are necessary for operational use, come at arbitrary points whose appropriateness is subject to question.

Actually, the fuel keys have two safeguards that taxonomic keys lack: (1) several different paths can lead to essentially the same ratings, so that a single "wrong" turn does not necessarily invalidate final readout; and (2) inaccuracies in single ratings should tend to average out when areas are sampled at a number of points.

Uses of Fuel Keys

Fuel keys constitute a recognition scheme, not a fuel appraisal system. However, the keys proposed here embody the same principles of fuel measurement that the ultimate appraisal system is expected to use.[12] The main differences are (1) the keys use descriptive terms where the ultimate system will have measurements, and (2) ratings given by the keys are relative and tentative, based on preliminary calculations, where the ultimate system will have estimates of absolute figures established through theory and experimentation. Therefore, the keys can be used as a partial preliminary version of the fuel appraisal system and, being compatible in form and output, as an adjunct of the ultimate system for certain purposes.

Training

Fuel keys may be of greatest value as training aids because they establish a disciplined, objective approach to fuel appraisal. The user progresses by a series of simple decisions to recognition and evaluation of highly complex fuel bodies. Standardized terminology, relevant only to fuel evaluation, is used in logical sequence. Equally important, concepts and information not required for physical description and evaluation of the fuels themselves are not introduced, however important they may be for determining fire behavior, e.g., the direct and indirect effects of topography. Thus, after learning only a few basic "building blocks" and the scheme of fitting them together, the beginner is equipped to recognize significant combinations of fuel characteristics anywhere. By contrast, existing fuel "classification" systems rely on memorizing intraregional fuel types on the basis of general appearance, and knowledge of the fuels of one region is seldom fully applicable in another.

Limited instructional experience incidental to testing suggests that people learn to use the keys readily. If anything, those with the least prior knowledge of fuel evaluation learn most rapidly, apparently because they (1) are devoid of prejudice and (2) do not have enough knowledge to try and extend the keys beyond their intended scope. Users quickly learn the early stages of a key so that they make rather complicated determinations by means of only two or three terminal steps and may not need the key at all for recurrent simple determinations. One critic's comment, that "we come to a degree of simplicity that borders on ridiculous," may be the ultimate recommendation of the fuel key as a training medium.

Inventory

The results of field testing suggest that fuel keys can be used to make consistent, reasonably accurate fuel inventories. Average fuel ratings for accepted vegetative types can be obtained from only a few observations; 10 appear adequate in rather uniform fuels, but more would be necessary where the range of possible individual ratings is great, as in logging slash. One milacre appears to be about the optimum size for rate-of-spread plots. Larger plots vary so much internally that it is difficult to select the representative condition;

[12] *Preliminary report of Forest Fuels Work Conference of March 3-7, 1969, on file in USDA Forest Service Division of Fire and Atmospheric Science Research, Washington, D.C.*

smaller ones exaggerate interplot variation so that number of observations needed to give a reliable average becomes excessive. Variation between plot ratings, and especially the frequency and location of very low ratings, will provide an estimate of fuel-bed continuity, for what it may be worth.

Crowning potential can best be rated at points rather than on plots of a specified size. The rating depends on ability of fire to climb into the crowns, which may require ladder fuels on only one tree, and ability to spread through the crowns, which is a function of crown characteristics over considerable area.

Fire Reconnaissance

Acquisition of detailed fuel information for use in controlling wildfires is a specialized form of fuel inventory that puts a premium on speed and recognition of features that significantly influence strategy and tactics. Line scouts and other overhead on large fires commonly are a heterogeneous lot in terms of experience and basic knowledge; extraregional overhead may never have seen the fuels they must contend with. Fuel keys can provide a common basis for understanding that will prevent serious errors in judgment. Some preliminary coordination is necessary, mainly to get general understanding of what elements of green vegetation will burn under existing and expected weather conditions.

Interfunctional Understanding of Fuels

If they prove to be as good a training medium as expected, the keys can be used to bring much-needed understanding of fuels by people engaged in all phases of forest land management and use. Resource managers continually manipulate vegetation, thereby changing fuel characteristics and often strongly influencing the ability to protect the forest (or other wild land) from fire. The change may require corrective action that becomes a big, unexpected cost item to the operation, as when precommercial thinning slash must be abated. Failure to anticipate the necessary action occurs largely because resource managers tend to be unaware of the consequences of their fuel-modification activities, which also have commonly been overlooked by research in the resource management fields. Few people outside the fire control function have ever learned to understand existing fuel classification schemes.[13] The ratings (H-H, M-L, etc.) are incomprehensible to them, and they hesitate to accept so subjective a method for making evaluations. The fuel keys can provide the common basis of understanding, with a familiar, reasonably objective rationale.

Interregional Coordination

The keys can serve temporarily as a common base for comparing regional fuel types until a national fuel appraisal system is developed. Key ratings of typical fuels in the field, or even from standard photographs, would establish the place of each regional type in the national scale. It would be equally possible to apply the keys to areas where fuels are described in locally familiar terms, e.g., where the relation of fire behavior to forest type is well known and no separate fuel evaluation system exists (Van Wagner 1965). The coordination, although perhaps crude, would give a national agency like the Forest Service its first opportunity to compare the fuel component of the fire problem among regions as a partial basis for equitable allocation of protection effort.

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[13] *Rather surprisingly, the regional fuel classification schemes have rarely been made generally available through formal publication. Distribution has been mainly within the fire control divisions of the U.S. Forest Service and other public protection agencies.*

Discussion

The principle of using keys to *identify and describe* materials is both proven and widely used; its effectiveness depends on terminology that permits clear discrimination between significant conditions or levels of the same conditions in the material. Such terminology for forest fire fuels has not existed heretofore. Therefore, an important contribution of this paper is the proposal and definition of terms that can be used universally to describe fuel characteristics.

Only two keys are presented — the intent being mainly to illustrate the principle rather than to suggest that here is a descriptive system for fuels, all ready for use. Even the crudely calculated rate-of-spread values used here suggest that some distinctions made in the key are insignificant and that some significant distinctions may have been omitted. Nevertheless, the keys do identify fuels in terms of conditions that are recognizable in the field and essentially independent of specialized technical knowledge. Therefore, as research provides increasingly accurate quantitative definitions of terms, clearer distinctions can be made and the keys can become logical frameworks for displaying fuel data and calculating the effects of fuels on forest fire phenomena. Additional keys can be developed as needed, relating to, say, ignition probability, fire intensity, and resistance to control; or, conceivably, increased knowledge may permit eventual consolidation of all information into one master key that will serve all purposes.

The key approach to fuel description is straightforward and simple in concept, but it further emphasizes that full description of even a rather simple fuel involves cognizance and interrelation of much detailed information. This fact helps to explain why use of fuel information in forest fire control has lagged and accounts for the constant earnest plea by protectionists that fuel appraisal systems be kept simple.

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Supplemental Set of Keys for Field Use

KEY NO. 1: RATE OF SPREAD

	Rating
A. Fuel essentially confined to surface layer — B	
B. Fine fuel present, not sparse — C	
C. Fine fuel fluffy (1) (fig. 1a, b)	100
CC. Fine fuel jumbled (2) (fig. 1b, c)	18
CCC. Fine fuel thatched — D	
D. Small fuel jumbled (3)	10
DD. Small fuel, if present, not jumbled (4) (fig. 1d)	5
CCCC. Fine fuel compact — E	
E. Small fuel jumbled (5) (fig. 2a)	5
EE. Small fuel thatched (6)	3
EEE. Small fuel sparse or absent — F	
F. Medium fuel jumbled (7) (fig. 2b)	3
FF. Medium fuel not jumbled (8) (fig. 1e)	1
BB. Fine fuel sparse or absent — G	
G. Small fuel jumbled or thatched (9)	3
GG. Small fuel sparse or absent — H	
H. Medium fuel jumbled (10)	2
HH. Medium fuel not jumbled — I	
I. Larger fuel jumbled (11)	1
II. Larger fuel not jumbled (12)	<1
AA. Fuel available in low and/or intermediate layers — J	
J. Low dense or open; intermediate fuel sparse or absent — K	
K. Fine low fuel dense to open — L	
L. Fine low fuel dense — M	
M. Surface fuel present, not sparse — N	
N. Surface fuel fine and/or small (13) (fig. 3a, c)	100
NN. Surface fuel medium and larger (14)	80
MM. Surface fuel sparse or absent (15) (fig. 3b)	65
LL. Fine low fuel open — O	
O. Surface fuel present, not sparse — P	
P. Surface fuel fine and/or small — Q	
Q. Surface fuel fluffy (16)	100
QQ. Surface fuel jumbled or thatched (17)	75
QQQ. Surface fuel compact (18)	50
PP. Surface fuel medium and larger (19)	40
OO. Surface fuel sparse or absent (20)	30
KK. Fine low fuel sparse or absent — R	
R. Small low fuel dense — S	
S. Surface fuel present, not sparse — T	
T. Surface fuel fine and/or small — U	
U. Surface fuel fluffy (21)	100
UU. Surface fuel jumbled or thatched (22)	50
UUU. Surface fuel compact (23)	30
TT. Surface fuel medium or larger (24)	30
SS. Surface fuel sparse or absent (25)	20
RR. Small low fuel not dense — A	
JJ. Low fuel and fine and small intermediate fuel dense or open — V	
V. Low fuel fine and/or small — W	
W. Surface fuel present, not sparse — X	
X. Surface fuel fine and/or small (26) (fig. 3d, e)	100
XX. Surface fuel medium and larger (27)	90
WW. Surface fuel sparse or absent (28) (fig. 3f)	70
VV. Low fuel medium and larger — Y	
Y. Surface fuel present, not sparse — Z	
Z. Surface fuel fine and/or small — a	
a. Surface fuel fluffy or jumbled (29)	100
aa. Surface fuel thatched or compact (30)	80
ZZ. Surface fuel medium and larger (31)	65
YY. Surface fuel sparse or absent (32)	50
JJJ. Low fuel sparse or absent; fine and small intermediate fuel plentiful — b	
b. Ladder fuels present — c	
c. Fine and/or small surface fuels present, not sparse — d	
d. Surface fuel fluffy or jumbled (33)	100
dd. Surface fuel thatched or compact (34) (fig. 4a)	80
cc. Fine and/or small surface fuel sparse or absent — e	
e. Medium and larger surface fuels jumbled (35)	60
ee. Medium and larger surface fuels not jumbled (36)	40
bb. Ladder fuels absent — A	

KEY NO. 2: CROWNING POTENTIAL

	Rating
A. Foliage present, trees living or dead — B	
B. Foliage living — C	
C. Leaves deciduous or, if evergreen, usually soft, pliant, and moist; never oily, waxy, or resinous (1)	[a]0
CC. Leaves evergreen, not as above — D	
D. Foliage resinous, waxy, or oily — E	
E. Crowns dense — F	
F. Ladder fuels plentiful — G	
G. Canopy closure >75 percent (2)	9
GG. Canopy closure less (3)	7
FF. Ladder fuels sparse or absent — H	
H. Canopy closure >75 percent (4)	7
HH. Canopy closure less (5)	5
EE. Crowns open — I	
I. Ladder fuel plentiful (6)	4
II. Ladder fuels sparse or absent (7)	2
DD. Foliage not resinous, waxy, or oily — J	
J. Crowns dense — K	
K. Ladder fuels plentiful — L	
L. Canopy closure >75 percent (8)	7
LL. Canopy closure less (9)	4
KK. Ladder fuels sparse or absent — M	
M. Canopy closure >75 percent (10)	5
MM. Canopy closure less (11)	3
JJ. Crowns open — N	
N. Ladder fuels plentiful (12)	3
NN. Ladder fuels sparse or absent (13)	1
BB. Foliage dead — O	
O. Crowns dense — P	
P. Ladder fuels plentiful — Q	
Q. Canopy closure >75 percent (14)	10
QQ. Canopy closure less (15)	9
PP. Ladder fuels sparse or absent — R	
R. Canopy closure >75 percent (16)	8
RR. Canopy closure less (17)	4
OO. Crowns open — S	
S. Ladder fuels plentiful (18)	6
SS. Ladder fuels sparse or absent (19)	2
AA. Foliage absent, trees dead — T	
T. Average distance between trees 33 feet or less — U	
U. Ladder fuels plentiful — V	
V. Trees with shaggy bark and/or abundant tinder (20)	10
VV. Trees not as above (21)	8
UU. Ladder fuels sparse or absent — W	
W. Trees with shaggy bark and/or abundant tinder (22)	10
WW. Trees not as above (23)	5
TT. Average distance between trees >33 feet (24)	2

[a] *Rare instances have been reported, resulting from extreme drought.*

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USDA Forest Service Research Paper PNW–100

FORTY-YEAR DEVELOPMENT OF DOUGLAS-FIR STANDS PLANTED AT VARIOUS SPACINGS

by Donald L. Reukema

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Forest Service U.S. Department of Agriculture

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INTRODUCTION

As the need for intensive management of timberlands becomes more evident, the effect of initial plantation spacing and/or early thinning on subsequent stand development is of increasing interest and importance to the land manager. Douglas-fir stands planted in 1925 at Wind River, near Carson, Wash., have been observed periodically for over 40 years and provide an increasingly valuable record of benefits derived from fairly wide, uniform spacing. Earlier results were reported by Isaac (1937), Munger (1946), Eversole (1955), Reukema (1959), and Morse.[1/]

During recent years, diameter and height growth of even the 100 largest trees per acre and total basal area and cubic volume growth per acre have all been substantially greater on the wider spacings. Furthermore, a great share of the total volume produced in the closer spacings is not merchantable.

THE STUDY

Study Area

The spacing test plantations occupy a site IV alluvial flat at an elevation of about 1,350 feet. The soil is a loose sandy loam with sporadic admixture of basaltic gravel and cobble. This juvenile soil is developing on pumiceous alluvium which is generally 4 to 7 feet deep and underlain by lightly fractured, basaltic rock.[2/] Felled timber on the area was accidentally burned in 1920, after which all usable material was salvaged. In 1924, the area was reburned by a very intense fire that destroyed all reproduction and burned all duff and debris down to mineral soil.

Treatment

In the spring of 1925, 1-1 seedlings were planted in 2.8-acre blocks at spacings of 4 by 4, 5 by 5, 6 by 6, 8 by 8, and 10 by 10 feet. A 0.5-acre block was planted with surplus stock at 12- by 12-foot spacing. These seedlings were started in the Wind River Nursery from seed of an unknown source near Roy, Wash. Extra seedlings were held in the nursery for subsequent replacement of failures.

[1/] Morse, J. E. An economic model for optimum initial spacing in forest plantations. 226 pp. 1962. (Unpublished M.F. thesis on file at College of Forestry, New York State Univ., Syracuse, N.Y.)

[2/] Personal communication with Richard E. Miller, Soil Scientist, Pacific Northwest Forest & Range Experiment Station, Olympia, Wash.

Sampling and Measurements

Different sampling systems were used as the study progressed, introducing some inconsistencies in reported results. At ages 7, 12, and 17 (years from seed germination), seedling heights were measured on selected rows of trees throughout each spacing. At age 23 (1945), three 1/4-acre plots were established in each spacing, except the 12 by 12 which contains a single 0.4-acre plot (fig. 1). In that year, diameters were measured on all trees on plots in the 8 by 8 through 12 by 12 spacings, but on only a systematic sample of rows on plots in the 4 by 4 through 6 by 6 spacings. At age 29 (1951) and subsequently, diameters of all trees in each plot were measured. Also in 1951, plot 17 was added in the 8 by 8 spacing as a substitute for plot 12, which was thought to be on lower quality site. Heights since 1945 have been measured on varying numbers of trees (minimum of 10 per plot) distributed across the entire d.b.h. range.

All volumes for the period 1945-65 were recomputed by means of tarif equations developed by Turnbull and Hoyer (1965). Average tarif numbers for each spacing and period were determined from trees measured for height; these averages were then smoothed over time to remove inconsistencies due to different samples measured. It was assumed, but not confirmed, that bole-form of trees of a given d.b.h. and height had not been influenced by spacing.

Other measurements have also been made on these plots. Crown dimensions were measured on selected trees at ages 12 through 29. In 1967, crown and stem dimensions were measured on about 36 trees for each spacing, equally distributed among plots and across the d.b.h. range therein, to determine the effect of spacing on stem-crown relationships. Results of this study are reported by Curtis and Reukema.[3/] Also in 1967, locations of all trees on plots plus 20-foot buffer strips were stem-mapped.

RESULTS AND DISCUSSION

Primary interest centers around the effect of spacing on usable yield. However, because merchantability standards vary, emphasis was placed on total yield, supplemented by *examples* of spacing effects on merchantable yield. Stand growth and yield will be discussed first, followed by discussion of their component parts--mortality and individual tree diameter and height growth.

Although the subject of this paper is stand development over the 41 years since planting seedlings, emphasis is placed on development during the most recent 14 years (ages 29-43), which clearly illustrates current trends. Earlier data, based on different sampling systems, are not directly comparable.

[3/] Robert O. Curtis and Donald L. Reukema. Crown development and site estimates in a Douglas-fir plantation spacing test. (Submitted to Forest Science for publication.)

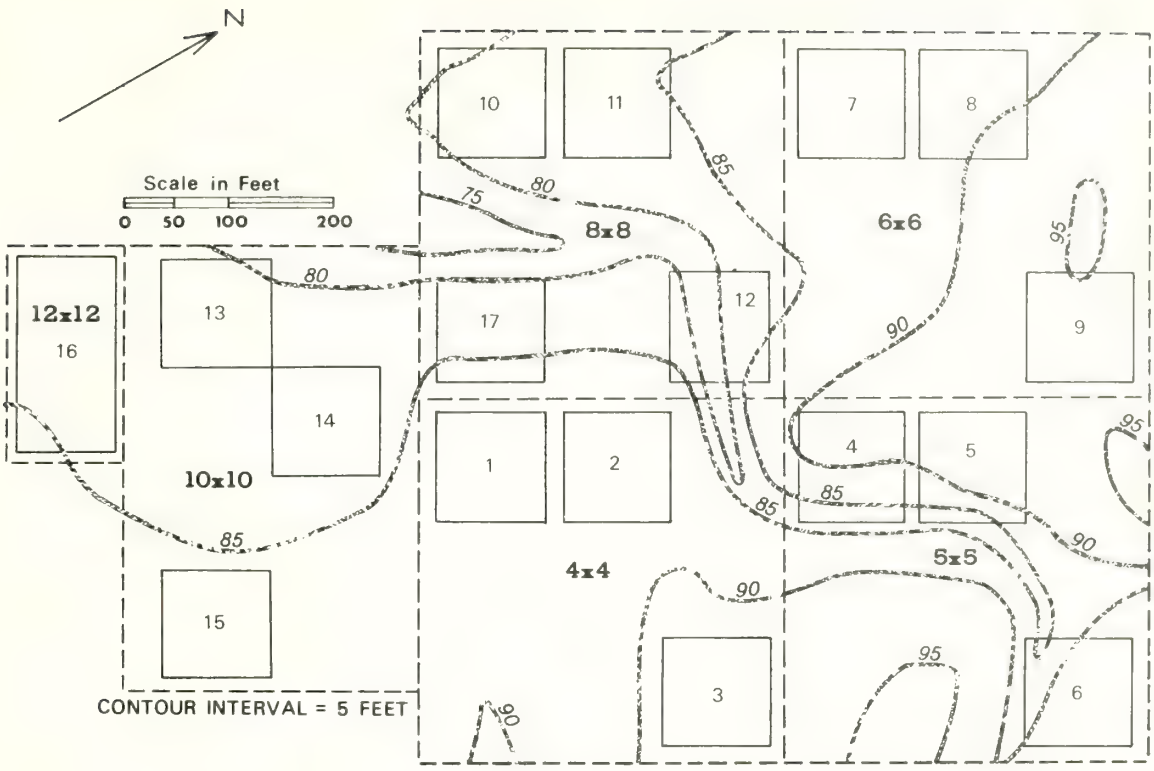


Figure 1.—Layout of Wind River Douglas-fir plantation spacing test.

Readers desiring information on how these findings relate to the general body of knowledge on spacing effects are referred to reviews by Reukema (1967) and by Sjolte-Jorgensen (1967). It is sufficient here to say that, although these results are contrary to widely accepted hypotheses, they support an increasing body of evidence that it may be commonplace for maximum production on low site-quality land to be attained through much wider than normal spacing of trees.

Growth and Yield

There have been fairly clear trends of increasing stand growth with decreasing stand density (number of trees), especially during the last 5 years. These general trends are elaborated in the succeeding sections. Differences in average tree dimensions and stand productivity among plots within spacings probably result from a combination of localized variations in site quality and in past injuries and mortality influencing stand density, stocking, and development.

Although the area is believed to be of quite uniform site quality, there are apparent minor local variations. There is no indication of any gradient across spacings, but there is considerable evidence that all 8 by 8 plots have somewhat lower than average site quality. In figures which follow, individual

plot values provide an index of variability. Superimposed on these bar graphs are curves which the author believes illustrate probable *trends* of production relative to spacing. Rather than passing through spacing averages, these curves reflect modification due to the aforementioned local variations.

Basal Area

Although *gross* basal-area yield per acre has always decreased with increasing spacing (fig. 2), the difference between the 4 by 4 and 12 by 12 spacings has narrowed from about 51 square feet at age 29 (1951) to 36 square feet at age 43 (1965). Widely spaced stands are currently growing more rapidly, so the difference should continue to lessen. During the 1960-65 period, gross basal-area growth was about 59 percent greater in the 12 by 12 than in the 4 by 4 spacing. Because of much greater mortality in close spacings, *net* basal-area yield is currently quite similar in all spacings, decreasing only slightly with increasing spacing.

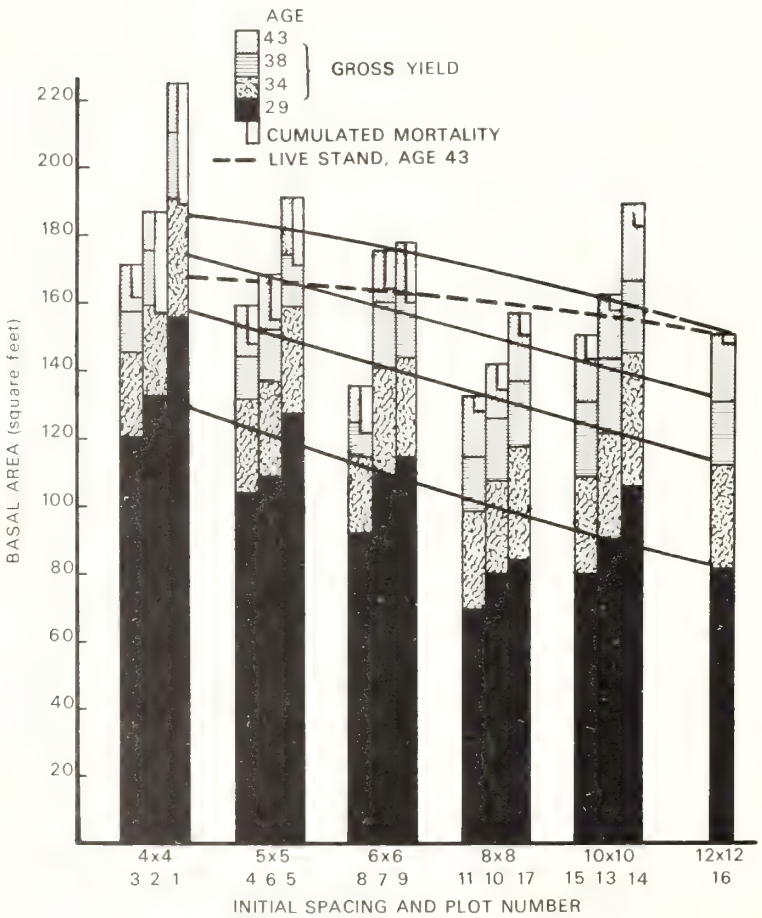


Figure 2.—Effect of spacing on basal-area yield per acre, by periods. (Gross yield at age 43 minus cumulated mortality = net yield.)

Cubic Volume

Gross cubic-volume yield at age 29 also decreased with increasing spacing (fig. 3). However, because of more rapid height growth on wider spacings, differences among spacings in volume growth have been greater than those in basal-area growth. Gross cubic-volume growth since age 29 has averaged about 70 percent greater in the 12 by 12 than in the 4 by 4 spacing. During the most recent period, gross cubic-volume growth was about 117 percent greater in the 12 by 12 than in the 4 by 4 spacing; differences between the 10 by 10 and 12 by 12 appear negligible. Thus, total gross cubic-volume yield of all trees 1.5-inch d.b.h. and larger (CVTS) now tends to *increase* with increased spacing. Total gross cubic-volume yield at age 43 was about 18 percent greater in the 12 by 12 than in the median 4 by 4 spacing (4,775 vs. 4,060 cubic feet). Whereas, gross mean annual increment is now apparently near culmination on close spacings, it is still increasing substantially on wide spacings (table 1). The sharp decline in periodic annual increment on all spacings during the most recent period is probably due largely to climatic influences.

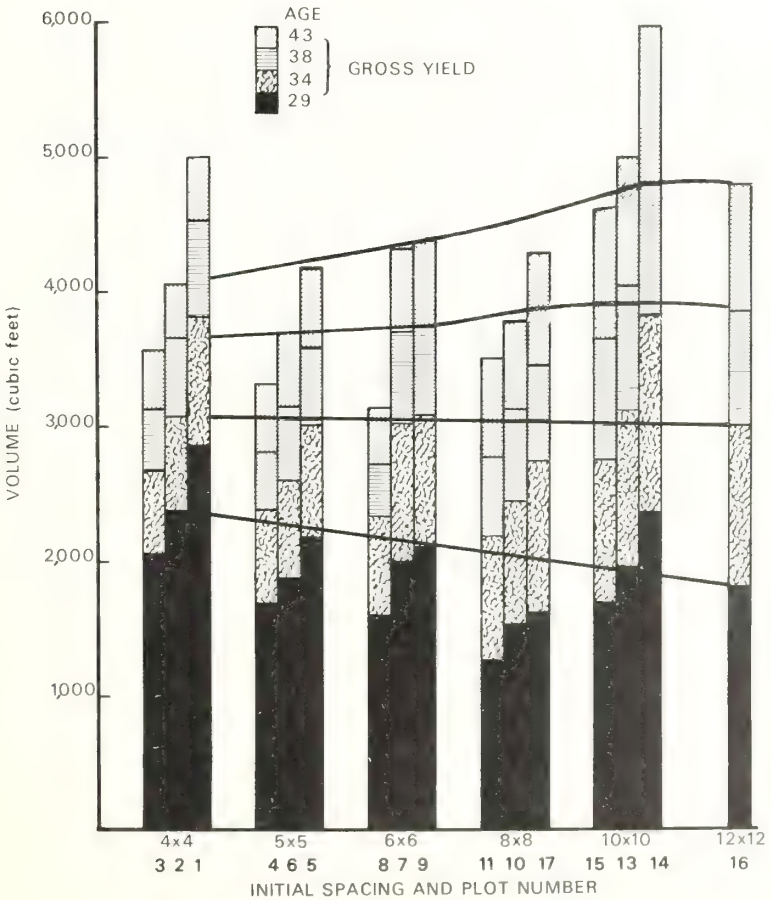


Figure 3.—Effect of spacing on total cubic-volume yield per acre, by periods.

Table 1.--*Gross periodic annual and mean annual increment, Wind River spacing test*

Spacing (feet)	Periodic annual increment by age				Mean annual increment by age				
	23-29	29-34	34-38	38-43	23	29	34	38	43
	Cubic volume per acre[1/]								
4 by 4	150	151	156	82	67	84	94	99	98
5 by 5	150	151	138	106	44	66	78	84	87
6 by 6	156	183	154	106	42	66	83	89	92
8 by 8	133	196	176	141	26	51	72	82	90
10 by 10	198	244	252	195	35	69	95	110	121
12 by 12	178	238	225	179	32	62	88	101	111

[1/] Average increment on plots representing each spacing.

If current growth trends continue, the difference in gross yield will continue to increase in favor of wide spacings. Because of heavier mortality on the closer spacings, increase in net cubic-volume yield with increased spacing is even greater. This indicates the superiority of wide spacings, no matter what merchantability standards may be applicable.

Merchantable Volume

When we impose merchantability standards, the economic advantages of wider spacings become even more impressive (figs. 4 and 5). If we use volume to a 4-inch top of trees larger than 5.6-inch d.b.h. as a minimum standard, current merchantable volume (CV4) ranges from about 1,500 cubic feet on the 4 by 4 to 4,350 cubic feet on the 12 by 12 spacing. About 58 percent of the live volume on the 4 by 4 spacing is nonmerchantable, compared with only 8 percent on the 12 by 12; corresponding nonmerchantable volumes are 2,750 and 430 cubic feet. Although most of the current growth in all spacings is now being added to merchantable volume, past nonmerchantable production is mostly lost. If we use a larger minimum top diameter as a standard, a greater portion of the total volume is, of course, nonmerchantable. For example, with a 6-inch top limit (CV6), 92 percent of the volume on the 4 by 4 as against 22 percent on the 12 by 12 is currently nonmerchantable.

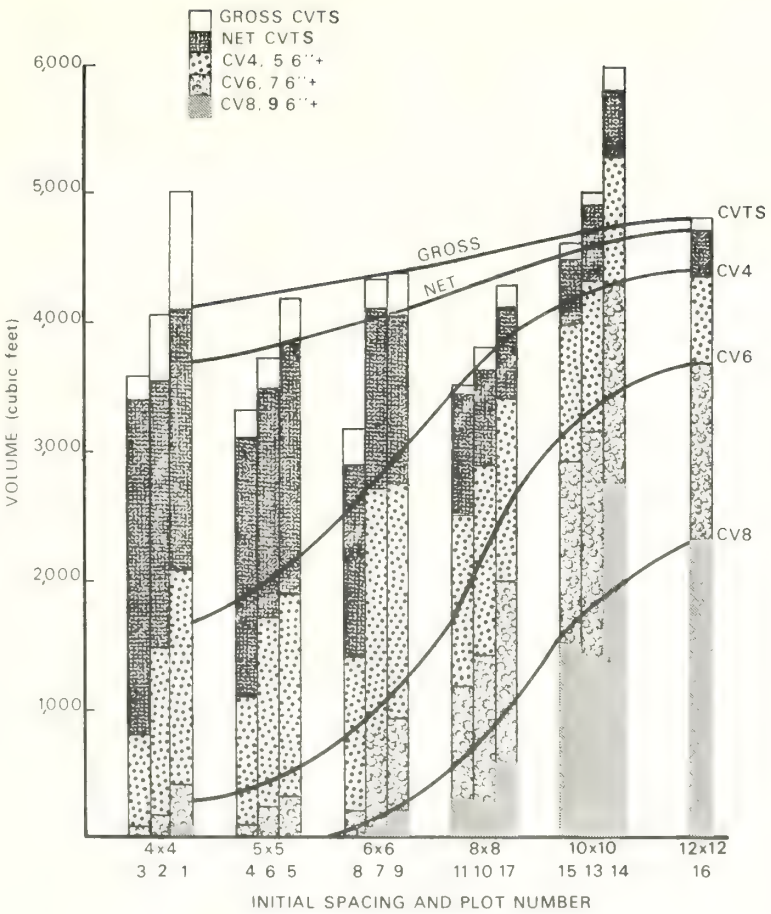


Figure 4.—Effect of spacing on total and merchantable cubic-volume yield per acre at age 43.

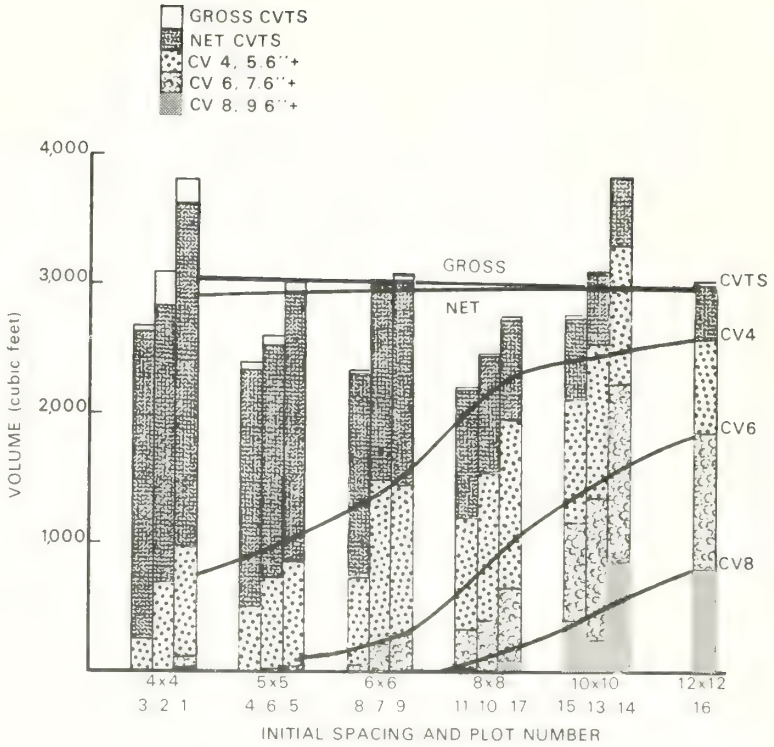


Figure 5.—Effect of spacing on total and merchantable cubic-volume yield per acre at age 34.

(CVTS = cubic volume of the total stem of all trees 1.5-inch d.b.h. and larger; CV4 = cubic volume to a 4-inch top of trees 5.6-inch d.b.h. and larger; CV6 = cubic volume to a 6-inch top of trees 7.6-inch d.b.h. and larger; CV8 = cubic volume to an 8-inch top of trees 9.6-inch d.b.h. and larger.)

Mortality and Damage

First 5 Years

Due to heavy initial mortality, replacements were necessary for 5 consecutive years (1926-30) following planting (table 2). The first year, 36 percent of the seedlings died and were replaced. Many of the seedlings planted subsequently were to replace initial replacements, as there were spots, on ashy or shallow soil, where mortality occurred repeatedly.[4/] Unfortunately, we do not have a record of these locations.

After Stand Establishment

Occurrence of mortality and damage over the subsequent 36-year period was quite erratic, but totals do show a clear relationship to spacing.

Trees lost ranged from 15 percent on the 12 by 12 spacing to more than 25 percent on the closer spacings (table 3). Unfortunately, mortality occurring between ages 17 and 23 could only be estimated by subtracting number of live trees at age 23 plus mortality between ages 7 and 17 from the theoretical number planted. The resulting high estimate of mortality in the 4 by 4 spacing in the age 17-23 period probably reflects inconsistencies in number of trees planted rather than actual mortality.[5/]

During the most recent 20 years (1945-65), the portion lost was about twice as great on the 6 by 6 and closer spacings as on 8 by 8 and wider spacings, ranging from 9.1 percent on the 12 by 12 to 20.7 percent on the 4 by 4.

In addition to this mortality, the stands contain many damaged live trees. An average of 22 percent of the trees alive in 1965 had at some time suffered damage, mostly during the most recent period. The range, by plots, was 20 to 33 percent on the 4 by 4 through 6 by 6 spacings and 7 to 11 percent on the 8 by 8 through 12 by 12. The fact that not only the number but also the *proportion* of dead and damaged trees increases substantially with increasing number of trees, or closer spacing, indicates that the closely spaced trees are much more *susceptible* to damage and death than are widely spaced trees.

[4/] Leo A. Isaac and George S. Meagher. Progress Report No. 2, Spacing in Douglas-fir plantations. 1936. (Unpublished report on file at Pacific Northwest Forest & Range Exp. Sta., Olympia, Wash.)

[5/] If number of trees actually planted were 450-500 per acre less than the theoretical 2,722 (i.e., about 4.4-foot vs. 4.0-foot spacing), estimated losses would fall in line. This is a reasonable discrepancy when one plants at such close spacings.

Table 2.--*Replacements during first 5 years to maintain spacing, Wind River spacing test*

Year	Percent	Number	Suspected principal cause of mortality
1926	36	7,200	Drought
1927	17	3,300	Drought
1928	5	1,000	Drought
1929	4	730	Stock too large
1930	3	630	Shoestring fungus

Table 3.--*Distribution of mortality by spacing and age, 1930-65, Wind River spacing test*[1/]

Initial spacing (feet)	Age (years)							
	7-12	12-17	17-23	23-29	29-34	34-38	38-43	Total
	Number of dead trees per acre							
4 by 4	166	30	514	147	141	55	217	1,270
5 by 5	78	12	31	37	100	45	132	435
6 by 6	59	18	39	30	33	19	136	334
8 by 8	42	14	16	5	16	7	44	144
10 by 10	17	5	5	4	4	7	30	72
12 by 12	2	0	0	8	3	3	15	31
	Percent of original number planted							
4 by 4	6.1	1.1	18.9	5.4	5.2	2.0	8.0	46.7
5 by 5	4.5	.7	1.8	2.1	5.7	2.6	7.6	25.0
6 by 6	4.9	1.5	3.2	2.5	2.7	1.6	11.2	27.6
8 by 8	6.1	2.0	2.4	.7	2.3	1.0	6.5	21.0
10 by 10	4.0	1.1	1.1	.9	.9	1.6	6.9	16.5
12 by 12	5.0	0	0	2.6	1.0	1.0	5.0	14.6

[1/] Mortality occurring between ages 7 and 17 was estimated by a sampling of selected rows throughout the plantation, and that between ages 23 and 43 was recorded on permanent sample plots. Mortality between ages 17 and 23 was determined by subtraction from theoretical number planted.

Apparent Causes

Averaged for all spacings, 61 percent of all mortality during the last 20 years has been attributed to storm damage (breakage, bending, windthrow), 7 percent to normal suppression, and 2 percent to root rot *(Poria weirii)* (table 4). The causes of the remaining 30 percent have not been specified.[6/] Much was probably due to normal suppression; some was almost certainly due to storm damage. Possible association between storm damage and root rot as causes of mortality on these plots has not been assessed. Of the damaged *live* trees, 97 percent have been broken or bent by storms. The remainder have dead tops or sickly crowns.

Distribution by Tree Size and Crown Class

Mortality and damage were generally confined to lower crown class trees which had not reached a merchantable size. Average d.b.h. of dead trees, by spacing, ranged from 3.1 inches on the 4 by 4 and 5 by 5 to 4.9 inches on the 10 by 10. An average of only six trees per acre were of merchantable size (5.6-inch d.b.h. or larger) at the time they died. Similarly, an average of only 12 damaged live trees were of merchantable size. Distribution of these merchantable trees showed no relationship with spacing.

In an assessment of distribution of mortality and damage by crown class, it is appropriate to look at data for the most recent period (1960-65), since the bulk of mortality and damage occurred during this period. On the average, 18 percent of the previously undamaged live trees suffered storm damage during that time. Damage was more extensive than this in the closer spacings and less in the wider spacings (table 5). Distribution of total damage among crown classes was similar in all spacings, averaging 3 percent dominants, 28 percent codominants, 45 percent intermediates, and 23 percent suppressed. Expressed as a percent of previously undamaged trees, damage on the closer spacings was about equally distributed across the codominant, intermediate, and suppressed crown classes.

About 40 percent of the trees first damaged during the 1960-65 period had died by 1965. Many of the live damaged trees are expected to die during the next period, whereas some certainly will linger on and/or recover. Trees which died during this period as a result of current damage accounted for 67 percent of the total mortality in this period. The remaining 33 percent was primarily a result of previous damage; a little was due to normal suppression.

[6/] Very little of this unspecified mortality is recent; 53 percent occurred during the period 1945-51 and another 32 percent during 1951-56.

Table 4.--*Summary of mortality and damage during the last 20 years, by spacing and cause, Wind River spacing test*

Condition	Initial spacing in feet					
	4 by 4	5 by 5	6 by 6	8 by 8	10 by 10	12 by 12
	Number of trees per acre					
Dead:						
Broken	175	155	137	38	36	18
Bent or leaning	62	44	7	7	1	0
Uprooted	22	18	33	9	0	2
Suppression	46	15	13	3	1	2
Root rot	20	1	4	1	0	0
Unspecified	239	80	23	15	7	5
Total	564	313	217	73	45	27
Damaged:						
Broken	22	42	42	18	26	15
Bent or leaning	367	238	153	28	4	2
Sickly or dead top	7	6	5	1	1	5
Total	396	286	200	47	31	22

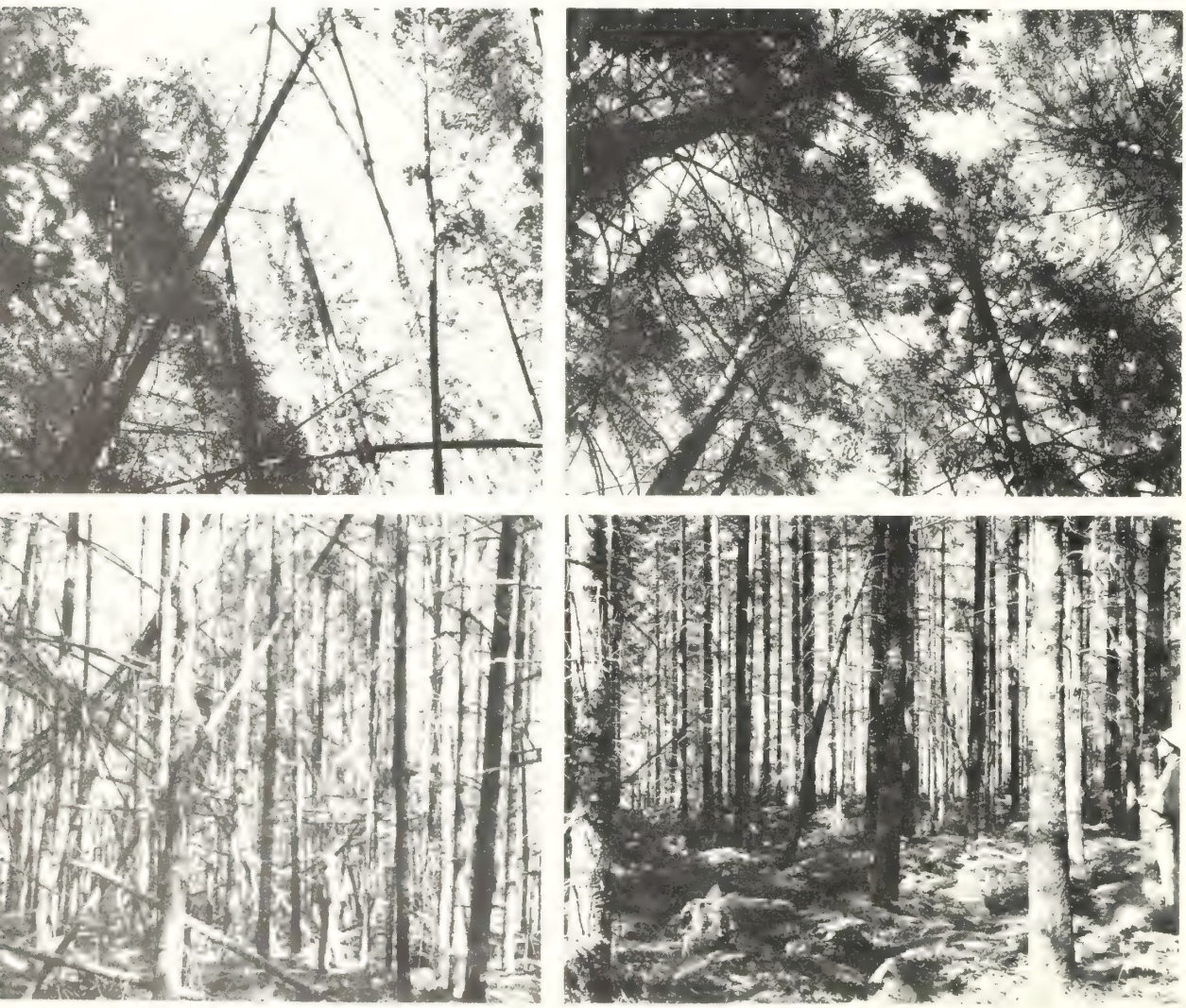
Table 5.--*Distribution among crown classes of trees first damaged during the period 1960-65, by spacing, Wind River spacing test*

Initial spacing (feet)	1960 crown class				
	Dominant	Codominant	Intermediate	Suppressed	Total
	Number of trees per acre				
4 by 4	20	132	203	92	447
5 by 5	5	91	92	92	280
6 by 6	5	49	105	31	190
8 by 8	1	3	26	10	40
10 by 10	1	8	16	4	29
12 by 12	0	0	7	0	7
	Percent of previously undamaged trees				
4 by 4	9	33	26	20	24
5 by 5	2	24	18	22	18
6 by 6	2	20	29	14	18
8 by 8	1	2	11	17	7
10 by 10	1	6	14	40	7
12 by 12	0	0	10	--	3

Impact on Growth and Yield

Because of the small size of most dead trees, the direct impact of mortality on volume yield to date has been rather slight. Losses during the 20-year period 1945-65, by spacing averages, amounted to only 1 to 12 percent of the total cubic-volume yield. However, the indirect impact of mortality and damage on growth capabilities and yield should not be dismissed. In the wider spacings, damage and mortality generally befell individual trees scattered through the stand--perhaps a beneficial natural thinning. In the close spacings, on the other hand, damage and mortality tended to occur in a clumpwise pattern, typically resulting from chain-reaction windthrow and breakage (fig. 6). Thus, openings created in the close spacings tended to be much larger than those in the wider spacings and took more area out of production. Furthermore, in close spacings, trees surrounding these openings have less vigorous crowns than those in wide spacings, so have been less able to respond to release received from these natural openings.

Figure 6.—Clumped damage was a common occurrence in the closer spacings (left), whereas there was little damage in the wider spacings (right).



Diameter

As would be expected, average d.b.h. of all trees 1.5 inches and larger was much smaller in close spacings than in wider spacings. But how has spacing influenced development of the largest trees in these stands? Average d.b.h.[7/] of the 100 largest trees per acre is commonly used as a measure of this effect. At age 29 (1951), average d.b.h. of the 100 largest trees per acre was 56 percent greater in the 12 by 12 than in the 4 by 4 spacing (8.9 vs. 5.7 inches). During the next 14 years, this lead increased to 67 percent (12.1 vs. 7.3 inches) (fig. 7). Growth rates of these trees continue to be greater with progressively wider spacing, so the differential among spacings will become greater. Largest trees on the 10 by 10 are growing at about the same rate as those on the 12 by 12.

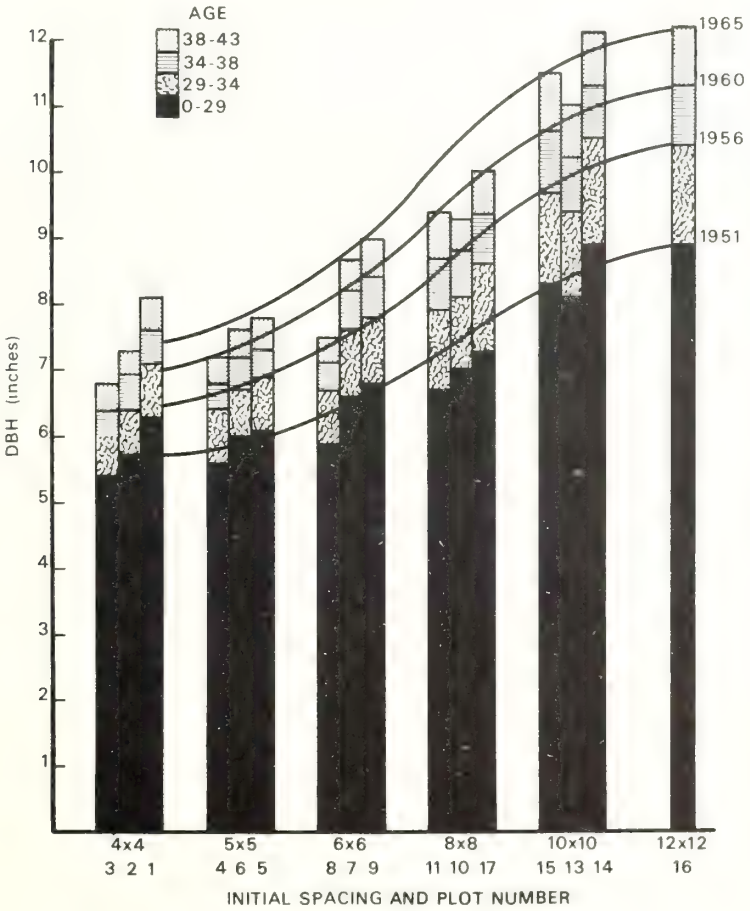


Figure 7.—Effect of spacing on average diameter growth of the 100 largest trees per acre, by periods.

[7/] Throughout this paper, average diameter refers to the d.b.h. of a tree of mean basal area (quadratic mean d.b.h.).

D.b.h. of the 100 largest trees per acre without regard to their distribution could be misleading, however, because these largest trees may occur in patches rather than well distributed over the area as commonly conceived. To assess the impact of this possibility, stem maps of each 1/4-acre plot were gridded into 25 squares, the largest tree in each square chosen, and the average d.b.h. of these well-spaced 25 trees (100 per acre) compared with those of the 100 largest trees per acre without regard to distribution (table 6). Average d.b.h.'s of the 100 largest well-spaced trees are 0.2 to 0.6 (averaging 0.35) inch less than those of the same number without regard to their distribution. Thus, if largest trees are used as a measure of productive capacity on these plots, use of a given number of largest trees without regard to their distribution leads to a slight overestimate. *Trends* in average d.b.h. of the 100 well-spaced largest trees per acre and of the 100 largest trees without regard to their distribution are very similar, however, justifying use of the latter for comparative purposes in this report.

Table 6.--*1965 average d.b.h. of the 100 largest and 100 well-spaced largest trees per acre, Wind River spacing test*

Initial spacing (feet)	Plot	100 well-spaced largest	100[1/] largest	Difference
		Inches		
4 by 4	1	7.9	8.1	0.2
	2	7.0	7.3	.3
	3	6.6	6.8	.2
5 by 5	4	6.8	7.2	.4
	5	7.5	7.8	.3
	6	7.4	7.6	.2
6 by 6	7	8.3	8.7	.4
	8	7.2	7.5	.3
	9	8.6	9.0	.4
8 by 8	10	9.0	9.3	.3
	11	9.0	9.4	.4
	17	9.6	10.0	.4
10 by 10	13	10.6	11.0	.4
	14	11.8	12.1	.3
	15	11.0	11.5	.5
12 by 12	16	11.6	12.2	.6

[1/] Without regard to their distribution.

Although spacing effects on diameter growth are, in some respects, most meaningfully expressed by comparison of equal numbers of largest trees, effects on development of smaller trees must also be considered. These trees contribute substantially to total production on closer spacings. For example, the 575 largest trees per acre on the 4 by 4 spacing contain about the same volume as 100 largest per acre on 12 by 12 spacing. This volume (2,680 cubic feet) is partly contained in trees of nonmerchantable size in the 4 by 4 spacing (where it includes 255 5-inch trees), whereas it is all in trees 11 inches and larger in the 12 by 12 spacing (fig. 8).

How much will these currently nonmerchantable trees contribute to future yield? During the 14-year period between ages 29 and 43, many trees on the closer spacings reached a merchantable size (5.6-inch d.b.h. and larger), whereas only a few additional trees on the wider spacings moved into this size class (fig. 8). Despite this ingrowth in closer spacings, however, increase in merchantable volume was more than twice as great on the wider spacings as on the closer spacings. Also, by age 43, there were still 1,137 live trees per acre *smaller* than 5.5-inch d.b.h. (i.e., the nonmerchantable component) in the 4 by 4, compared with only 10 per acre in the 12 by 12. Thus, although many trees in the close spacings reached merchantable size between ages 29 and 43, many more trees are still smaller than the accepted minimum. Furthermore, it is unlikely that most trees currently smaller than 4.5-inch d.b.h., along with many of those in the 5-inch class, will ever reach this merchantable size. Assessment of 14-year (1951-65) d.b.h. growth of all undamaged trees in all plots shows the very slow rate of growth being made by the small trees (fig. 9).[8/] Future growth will be even slower and natural mortality will remove many of these small trees.

Height

Height/diameter curves.-- Height/d.b.h. curves for all spacings at specified ages have always been very similar, indicating that effects of spacing on height growth have been nearly proportional to effects on d.b.h. growth. Thus, contrary to the commonly accepted view that height growth of dominant and codominant trees is not influenced by stand density, whereas diameter growth is, height in these stands can be fairly well predicted by diameter, regardless of stand density. Therefore, trends in diameter described previously are a preview to trends in height.

Despite the similarity among curves for the various spacings, there has been a clear trend of change over time (fig. 10). Height/d.b.h. curves at age 21 (1945) were progressively slightly *lower* with increasing spacing. Current height/d.b.h. curves are progressively slightly *higher* with increasing spacing. Thus, for a time, stand density did influence diameter growth more than height

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[8/] Deviations from this line show no consistent relationship to spacing of trees.

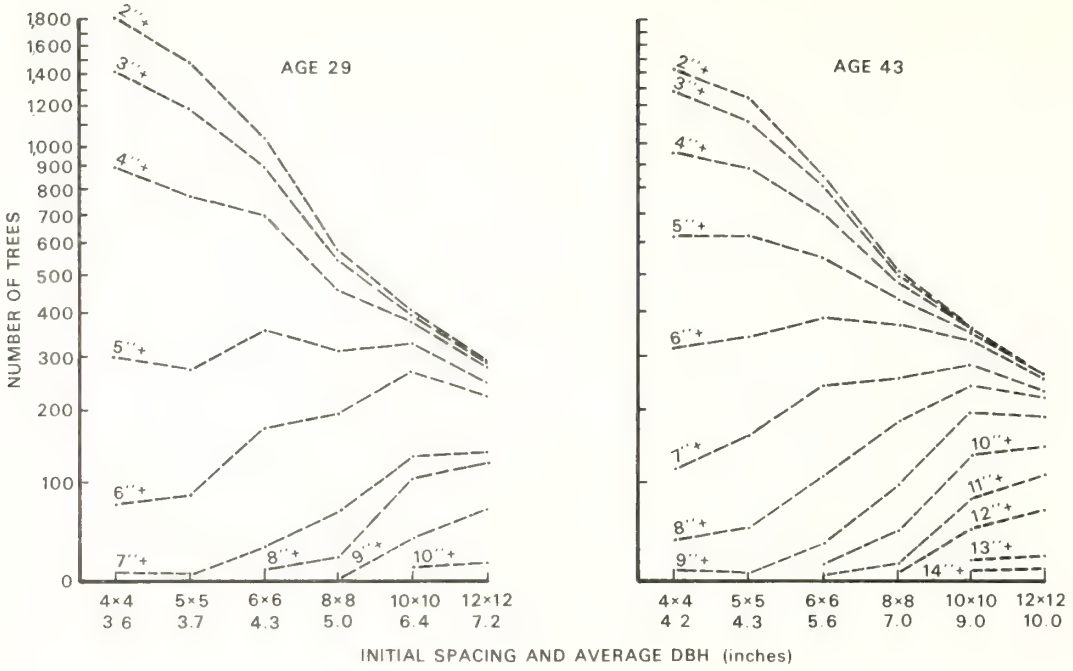

Figure 8.—Number of trees per acre larger than specified d.b.h. class at ages 29 and 43, by initial spacing.

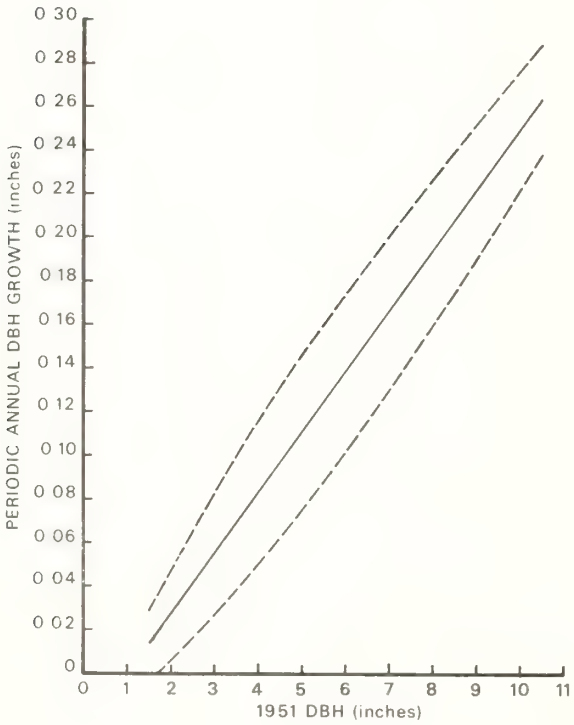

Figure 9.—Relationship of 14-year d.b.h. growth (1951-65) to 1951 d.b.h. (The band denoted by broken curves includes about 80 percent of the trees).

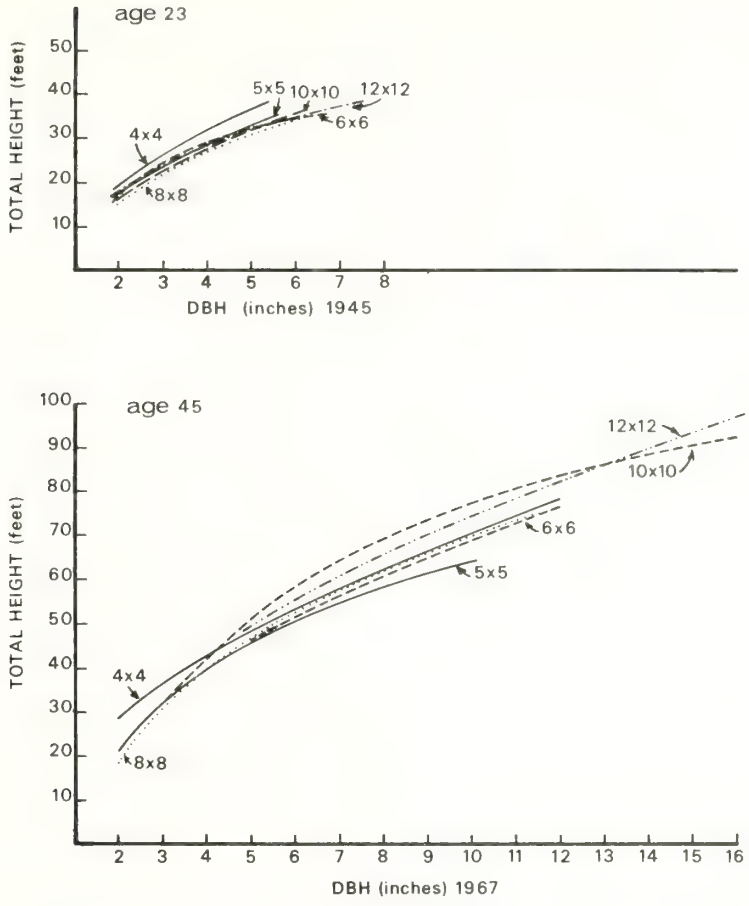

Figure 10.—Curves of height over d.b.h. at ages 23 and 45.

growth; but this is no longer true. More recently, height growth in the wider spacings has steadily improved relative to unmanaged stands (McArdle et al. 1961), whereas that in closer spacings has diminished. Height/d.b.h. relationships and comparable crown dimension/stem dimension relationships are discussed further by Curtis and Reukema (see footnote 3).

The 100 largest trees per acre.--At age 12, the 100 tallest trees per acre averaged about 12 feet tall, with those in wide spacings being slightly shorter than those in close spacings (table 7). Since that time, however, height growth of trees on wider spacings has been greater than that on close spacings. At age 29 (1951), heights of the 100 largest trees per acre in the 12 by 12 spacing were about 8 percent taller than those in the 4 by 4. By age 43 (1965), these trees were 39 percent taller in the 12 by 12 than in the 4 by 4 spacing (79 vs. 57 feet) (fig. 11).

Table 7.--*Average heights of the 100 largest trees per acre at ages 12 through 29*[1/]

Age	Spacing (feet)					
	4 by 4	5 by 5	6 by 6	8 by 8	10 by 10	12 by 12
12	12.6	12.9	12.7	9.9	11.5	10.9
17	22.3	22.3	21.9	18.6	22.2	21.7
23	32	33	34	31	37	36
29	48	44	45	46	52	52

[1/] Heights at ages 12 and 17 are for the 100 tallest trees per acre, as estimated on selected sample rows throughout the entire plantation. Heights at subsequent ages are for the 100 largest (d.b.h.) trees per acre, as estimated from height/d.b.h. curves derived from measurements on permanent sample plots.

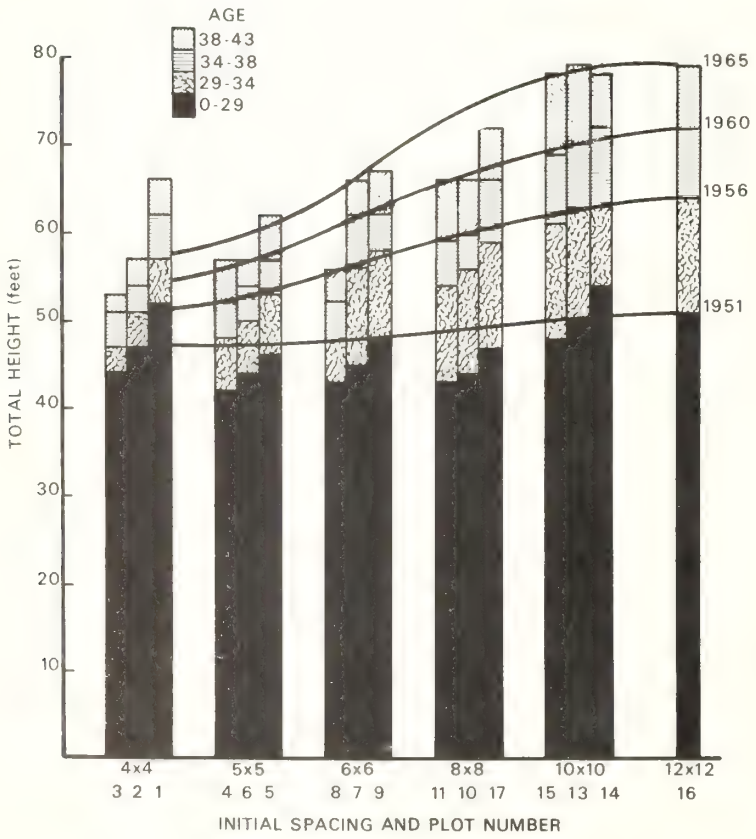

Figure 11.—Effect of spacing on height growth of the 100 largest trees per acre.

Prior to the onset of competition, one would expect about the same percent of all trees in each spacing to show superior height growth as a result of genetic and/or microsite variation. Thus, it is logical that during this period, the 100 tallest trees per acre were a little shorter in the wider spacings than in the closer spacings (table 7); these 100 trees were 33 percent of the total number in the 12 by 12 spacing, but only 7 percent of the total in the 4 by 4 spacing. That competition had begun even at an early age is exemplified by looking at the proportion of trees taller than some specified height, such as trees taller than 9.5 feet at age 12 and taller than 17.5 feet at age 17 (table 8). This not only illustrates the impact of competition on this relationship, as presumably reflected in lower percents in close spacings, but also illustrates the poorer than average condition of the 8 by 8 spacing.

Table 8.--*Relationship between spacing and tree height (acre basis); trees taller than specified height at ages 12 and 17; Wind River spacing test*

Spacing (feet)	Age 12, trees 9.5+ feet tall		Age 17, trees 17.5+ feet tall	
	Number of trees	Percent of total	Number of trees	Percent of total
4 by 4	463	17	426	16
5 by 5	364	21	317	18
6 by 6	256	21	235	19
8 by 8	46	7	65	10
10 by 10	111	25	168	39
12 by 12	85	28	139	46

CONCLUSIONS AND MANAGEMENT IMPLICATIONS

Whereas present (age 43) basal-area yields in this trial still decrease with decreasing density (number of trees), current total volume yields (both net and gross) increase with decreasing density, and the differences, in favor of wider spacings, are increasing with time. This is the result of greater height growth on the wider spacings. Merchantable volumes, of course, increase substantially with increasing spacing. The high nonmerchantable production on closer spacings represents a substantial waste.

Virtually all damage to surviving trees and over 60 percent of mortality have been attributed to storm damage. Trees in the closer spacings have been more susceptible to such damage, especially in more recent years. Most damage and mortality have been confined to trees which have not reached a merchantable size (5.6-inch d.b.h.). Mortality and damage in the closer spacings

have tended to be clumpy and have created large openings in the stand, thus taking part of the area out of production for a substantial period of time.

Diameter growth of even the largest trees is clearly affected by spacing. The 100 largest (d.b.h.) trees per acre are currently 67 percent larger in diameter (12.1 vs. 7.3 inches) and 39 percent taller (79 vs. 57 feet) on the 12 by 12 than on the 4 by 4 spacing. These differences, in favor of the wider spacings, are also increasing with time.

These conclusions indicate considerable gains to be derived from planting at uniform, fairly wide spacing or from making early thinning to such spacing. Total cubic-volume yields on the 10 by 10 and 12 by 12 spacings in this trial are currently about 20 percent above "normal" for site 110,[9/] and the difference is increasing with time. Furthermore, trees on the wide spacings are apparently of a quality equal to or better than those on close spacings. Trees on the wider spacings do not exhibit excessive taper or branchiness. Branches have died off to about the same height in all spacings and have attained only slightly larger diameter in wider spacings.

At close spacings, not only is total volume production less, but much of the production is wasted on many small trees which will never reach merchantable size. Whereas 84 percent of the trees planted at 12 by 12 spacing have reached a d.b.h. of 5.6 inches or larger, less than 12 percent of those planted at 4 by 4 spacing have reached this size. At least 20 percent of the present volume on the 4 by 4 spacing is in trees which will probably die without reaching merchantable size.

Even with wide spacings, growth of individual dominant trees has slowed down markedly. To prevent rapid decline of diameter growth rates, these stands should have been thinned. The 10 by 10 and 12 by 12 spacings could have supported commercial thinning at about age 30 and the 8 by 8 spacing could support such thinning now (age 43). Closer spacings, however, even now would not support commercial thinnings by current minimum merchantability standards.

The indicated responses are probably typical of what can be expected on most such low- to medium-quality sites. To maximize returns under such conditions, one should plant at wide spacing (10 by 10 to 12 by 12 feet or possibly wider), or make very early precommercial thinnings to such spacing in natural stands. If a market for small-sized thinning products (e.g., trees of 6-inch d.b.h.) is anticipated, probably about 10 by 10 spacing with an early start on commercial thinning is most desirable. If such a market is not anticipated, then returns will probably be maximized by planting at even wider spacing.

[9/] Height measurements in the surrounding stand, and early measurements in these plantations, indicate a maximum site quality of about 110 on McArdle's site index system (McArdle et al. 1961).

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1970

USDA FOREST

A NEW AND FASTER WAY TO ESTIMATE THE QUALITY OF INLAND DOUGLAS-FIR SAWTIMBER

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Paul H. Lane, Marlin E. Plank, and John W. Henley

PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION · PORTLAND, OREGON
FOREST SERVICE
U.S. DEPARTMENT OF AGRICULTURE

FOREWORD

Inland Douglas-fir constitutes an important part of the Nation's sawtimber resource. Some 6 billion board feet of inland Douglas-fir sawtimber are cut annually, of which a sizable portion (about 40 percent) is cut from Federal and State lands.

The public agencies and the forest industry are much concerned with how this timber is appraised for sale. An important and difficult part of the appraisal job is estimating the quality of a tract of timber in terms of the amount of the various grades of lumber or other primary products that can be produced from it.

The Forest Service in cooperation with other public agencies and the forest industry is conducting research to develop better methods for estimating the potential lumber and veneer grade yield from standing timber. This report describes progress in meeting this objective: the development of a better timber grading system for inland Douglas-fir sawtimber.

The tree grading system described employs a new concept for evaluating the quality of timber and promises to make the timber appraiser's job easier and more accurate. If this report stimulates questions, suggestions, or other comments, we shall appreciate having them.

PHILIP A. BRIEGLEB
Director

A common method of appraising individual tracts of sawtimber for sale is to start with an estimate of the selling value[1/] of the lumber that can be produced from the entire stand being sold. Stumpage value is then derived by subtracting such various estimated production costs as roadbuilding, logging, milling, and an allowance for profit and risk from the estimated lumber selling value.

The lumber selling value is usually determined by cruising all or a sample of the trees in the stand to obtain an estimate of the timber volume and quality. Volume is normally expressed in terms of board feet and derived by applying the cruise measurements of tree size to appropriate volume tables. Quality is estimated by applying a log grading system to the cruised trees. Dollar value is then determined by applying appropriate lumber prices to log grade lumber yield tables developed from mill recovery studies.

Most log grading systems for standing timber segregate sections of the stem or "logs" into discrete value classes. The timber cruiser determines the grade of each log in the tree--usually in 16-foot units. The standing tree log grades for inland Douglas-fir developed by the Pacific Northwest Forest and Range Experiment Station are an example of a discrete grading system.[2/]

This paper, written primarily for timber appraisers, describes a new and improved method for estimating the lumber selling value of individual tracts of inland Douglas-fir sawtimber. The method was developed as a companion or alternative to log grading.

The system differs from the conventional log grading procedure in two principal ways: (1) it provides a selling value estimate for each cruise tree as a unit--therefore, it is more appropriately designated a *tree* grading system than a *log* grading rule, and (2) the system does not group trees into restricted or discrete quality classes--it is a nondiscrete or a continuous system where the estimated value of each tree is in itself a "grade."

The following describes the system, its development, and some examples of its performance.

The System and How It Was Developed

The end product value of a tree is largely dependent on its physical (quality) characteristics and the way it is processed. The basis for developing a good

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[1/] Dollar value of lumber f.o.b. mill.

[2/] Paul H. Lane. Grades for inland Douglas-fir saw logs in standing trees. Pacific Northwest Forest & Range Exp. Sta., USDA Forest Serv. Res. Note PNW-19, 5 pp., 1964.

timber grading system is determining which tree and log characteristics are important and the relationship of these quality features to end product yield and value.[3/]

This tree grading system was developed by studying the quality characteristics and lumber yield from 1,099 inland Douglas-fir trees selected from typical commercial sawtimber stands. The trees were selected from 41 sample areas in Idaho, Montana, Oregon, and Washington (fig. 1). They were processed in a similar manner at four typical sawmills. Total lumber yield from the study trees was about 733,000 board feet.

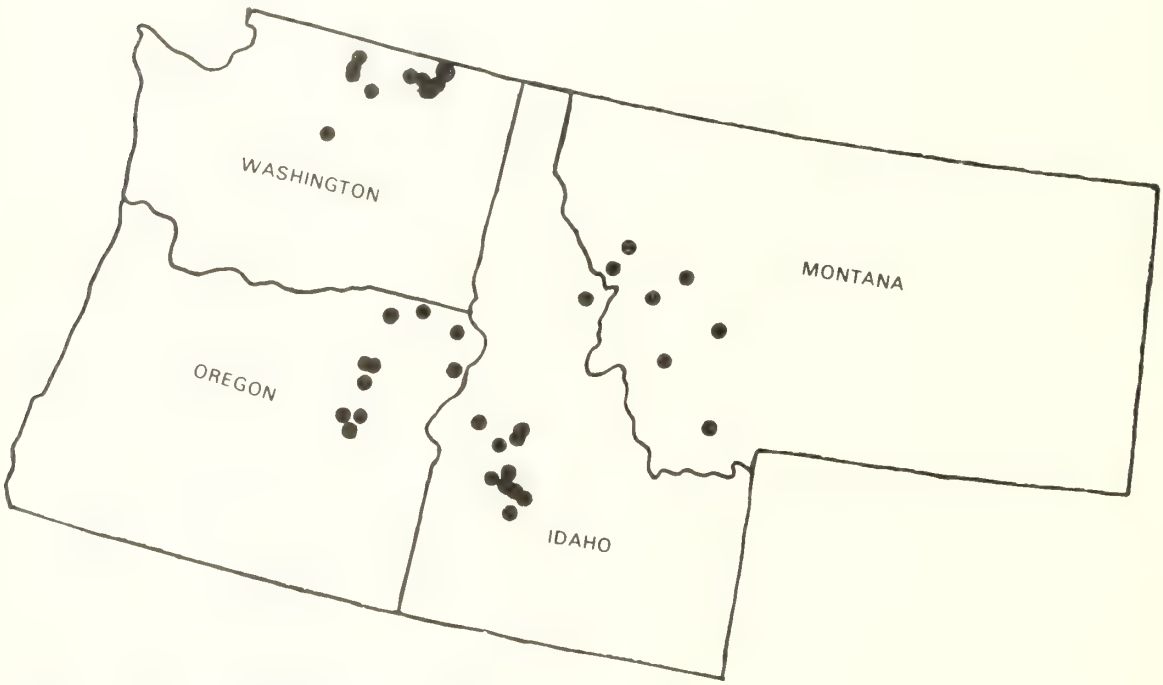

Figure 1.--General location of the 41 areas from which study trees were cut.

[3/] Paul H. Lane. Evaluating log and tree quality for wood products. Forest Prod. J. XIII(3): 89-93, illus. 1963.

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In the development of the grading system, multiple regression analysis was used to determine the relationship of many tree characteristics to the lumber yield. The characteristics that had little or no effect on lumber value, or were difficult or impossible to quantify in cruising, were screened out.

More than 30 independent variables quantifying the tree characteristics were investigated in the regression analysis. The principal dependent variables were total lumber value (dollars), total lumber volume, and various groupings of lumber grade volume.

Five quality characteristics survived as the most important and practical criteria for grading trees:

1. Tree diameter
2. Tree height
3. Basal scar length
4. Diameter of the largest limb (or limb stub) in the butt 16-foot portion of the stem
5. Defect

These five variables and the lumber yield data were used to develop a number of trial regression equations for predicting the total lumber tally volume (board feet), value (dollars), and the yield (board feet) of Standard and Better lumber on a tree basis. One equation was finally selected as being the most practical with respect to application in timber appraisals and as statistically accounting for the most variation in lumber volume and value. The equation for predicting tree value is:

$$\$ = a + b_1S + b_2H + b_3D + b_4L + b_5P + b_6D^2 + b_7P^2 + b_8DH + b_9D^2H$$

where

\$ is the predicted total dollar value of lumber recovery for an individual tree.

S is length of basal scar in feet.
H is tree height in feet.
D is tree diameter in inches at 4-1/2 feet above ground.
L is diameter of largest limb in inches in butt 16-foot log.
P is estimated percent defect of gross cruise volume.
a is constant for the Y intercept.
b's are the regression coefficients.

The *basal scar* specification refers to a characteristic commonly found in inland Douglas-fir. This type of timber defect is often described as a fire scar, cat face, or frost crack (fig. 2). Such scars generally indicate that the underlying wood is decayed, excessively pitchy, or severely checked to the extent that lumber recovery is affected.

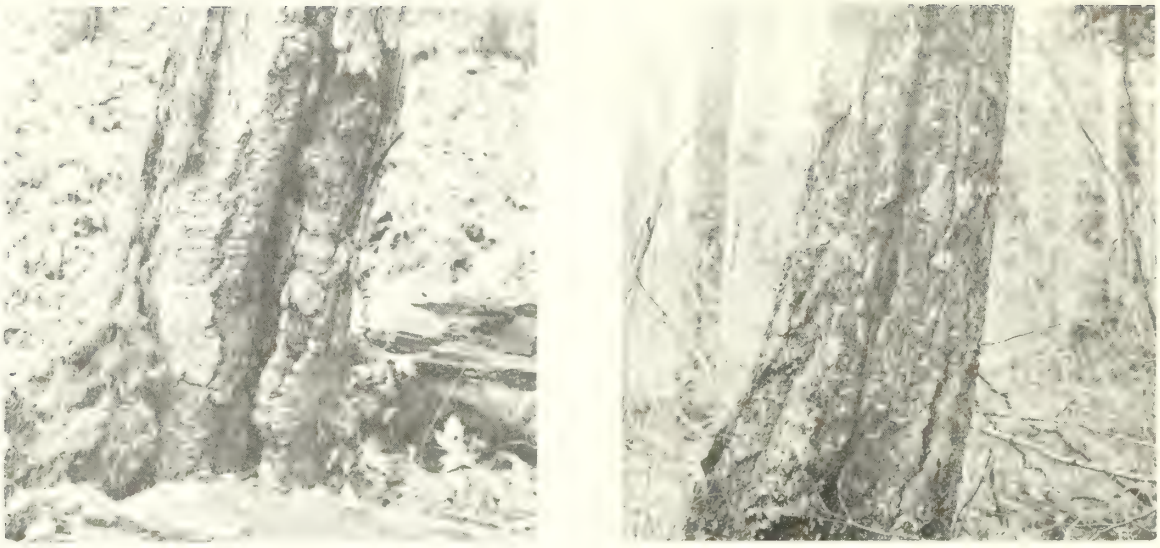

Figure 2.--Typical basal scars in Douglas-fir sawtimber.

A. Fire scar with decay.
B. Seam or "frost crack."
C. Scar commonly called a "cat face"--origin may have been from fire or mechanical damage.
D. Superficial (not degrading) scar caused by recent logging.

Fresh scars or injuries that, in the judgment of the timber cruiser, are superficial with respect to lumber recovery are disregarded.

The *limb* or limb stub specification is indicative of the size and character of knots that may be expected in the lumber produced. Knot size is directly related to lumber grade and value.

The *defect* estimate includes deductions made from the gross cruise volume for visible abnormalities such as crook, conks, cankers, burls, and bumps; and from the estimated volume loss from unknown sources such as logging breakage and hidden or internal defects such as shake, rot, and pitch rings.

The *a constant* identifies the appropriate Y intercept and indicates that a merchantable tree cannot have zero volume or value.

The *b*'s are the regression coefficients developed from a covariance analysis of the regression equations for each of the four base mill studies described previously. In application, they will vary according to the specific lumber prices used. Procedures for developing appropriate coefficients are included in the following section.

Two additional equations were developed to supplement this basic value prediction equation. They are (1) an equation to predict the total lumber tally volume of a tree, and (2) the volume of Standard and Better lumber grades. These two equations have the same form as the dollar value equation.

The equations developed from the four recovery studies account for 87 percent of the total variation in dollar value, 93 percent of the lumber volume variation, and 79 percent of the Standard and Better variation as measured by the regression R^2 values.

The system's simplicity affords considerable flexibility to fit any particular timber appraisal situation.

How To Use the System

Access to computer facilities for making regression analyses, covariance analyses, and solving equations is essential for efficient use of the system.

It will also be necessary to have, in a form suitable for computer use, the tree characteristic data (the five grading criteria) and lumber grade yield data for each of the 1,099 trees from the four mill studies used to develop this system. These data can be reproduced from a source deck of hollerith cards available for loan from the Timber Quality Research Work Unit, Pacific Northwest Forest and Range Experiment Station, P.O. Box 3141, Portland, Oregon 97208. The card format is illustrated in the appendix.

A step-by-step procedure for estimating the lumber volume and selling value of a group of trees or tract of timber is as follows:

1. Select an appropriate number of sample trees. Various timber cruising guidelines are available for choosing an adequate sample.[4/]

2. Measure and record for each sample tree the five characteristics: (1) scar length, (2) tree height, (3) tree diameter, (4) limb size, and (5) defect percent.

3. Assign desired lumber prices to each of the lumber grades (or combinations) recorded in the four base studies.

4. Using these assigned lumber prices, compute a total dollar value for each of the 1,099 trees from the four base studies.

5. Use an appropriate multiple regression program to develop the value equation coefficients for the 1,099 trees. Use assigned lumber prices (step 4) and the five tree characteristic variables and transformations as follows:

Independent

$$S$$
$$H$$
$$D$$
$$L$$
$$P$$
$$D^2$$
$$P^2$$
$$DH$$
$$\frac{1}{D^2H}$$

Dependent

Total dollars

All variables must be multiplied by $\frac{1}{D^2H}$ to equalize variance.

6. Make a covariance analysis of the four base study value equations to obtain appropriate coefficients for the common equation. Some computer programs will perform multiple regression and covariance analysis in one operation.[5/]

[4/] David Bruce. Charts for determining sampling rate and number in sample. Pacific Northwest Forest & Range Exp. Sta., USDA Forest Serv. Res. Note PNW-97, 6 pp. 1969.

[5/] Such as the Pacific Northwest Forest & Range Experiment Station's program RECO (CDC 6400 or IBM 7040).

7. Solve the value equation for the selected sample trees (step 1) using the covariance coefficients developed in step 6.

8. Predict the total lumber tally volume of each sample tree by using the equation with the following coefficients:

$$\begin{aligned}\text{Total lumber tally volume (bd. ft.)} = {} & -33.763095 - .522607(S) - .319531\ (H) \\ & +1.016213\ (D) - .083392\ (L) - .909085\ (P) \\ & - .124714\ (D^2) - .004588\ (P^2) + .060791\ (DH) \\ & + .010848\ (D^2H)\end{aligned}$$

9. Estimate the volume of Standard and Better lumber for each sample tree by using the equation with the following coefficients:

$$\begin{aligned}\text{Volume of Standard and Better (bd. ft.)} = {} & +88.638546 - 1.774408(S) - 4.104304\ (H) \\ & - 1.820890\ (D) - 2.823189\ (L) - 1.510553\ (P) \\ & - .563189\ (D^2) + .002798\ (P^2) + .434559\ (DH) \\ & + .002351\ (D^2H)\end{aligned}$$

How the System Performs

The major objective of a timber appraisal grading system is to predict the value of a group of trees (usually 50 or more depending on the size and variability of the stand to be sampled). Obviously, the predicted and/or actual value for any one tree in such a sample may vary considerably from the group mean value. This variation is due primarily to the defects and other inherent characteristics of the timber and the way it is manufactured.

To illustrate how this tree grading system performs, it was applied to three commercial timber sales having about the number of trees that might be selected as a sample in making the quality estimate in a typical inland Douglas-fir sale. On each sale, the five quality criteria measurements were recorded for the trees by the cruiser. Predictions of the lumber selling value and volume were then calculated using the procedures described above. The actual lumber selling value and volume information were obtained by sawing the sample trees in a typical mill. Comparisons of estimated and actual values are shown in table 1.

It is noteworthy that the deviations of estimated from actual are not biased in one direction--two estimates are a little higher than the actual and one is a little lower. The predictions of lumber value are well within what might be the expected performance standard of any grading system.

Table 1.--*A comparison of actual vs. predicted lumber selling value for three inland Douglas-fir timber sales*[1/]

Timber sale	Number of trees	Lumber value		
		Estimated	Actual	Percent difference
		- - - - *Dollars* - - - -		
Northeastern Montana	168	4,323	4,088	+5.7
Northern Idaho	45	2,128	2,229	-4.6
Flathead Lake area, Mont.	158	4,510	4,392	+1.0

[1/] Timber sales conducted in 1969 by the Northern Region, National Forest Systems, U.S. Forest Service, Missoula, Mont.

Conclusions

Field application tests of the system have demonstrated that it has a number of advantages over the conventional log grading method. It is faster to apply and therefore more economical; it requires less experience and judgment by the timber cruiser; and the training and checking of cruisers is easier.

Computation of the selling price also has some advantages over the conventional method of weighting the cruise volume by log grade and adjusting yield by log overrun estimates. Selling price is computed more directly; the quality characteristics of each sample tree are given more weight; and the computation procedures are relatively simple.

This system has been used successfully by the U.S. Forest Service and the timber industry for more than 2 years in computing the selling value of inland Douglas-fir on commercial timber sales in the northern Rocky Mountain area. Its performance and acceptance by both timber buyers and sellers indicate it is a relatively simple yet accurate method for estimating the quality of inland Douglas-fir sawtimber.

APPENDIX

The tree quality characteristic and lumber yield data for each of the 1,099 inland Douglas-fir trees from the four base studies are entered on punchcards according to the card format shown below.

Card columns	*Information*	
1	Study number	(X)
2-4	Tree number	(XXX)
5-6	Scar length	(XX)
7-9	Total height	(XXX)
10-12	D.b.h.	(XX.X)
13-14	Largest limb in butt 16-foot log	(X.X)
15-17	Percent defect	(XXX)
18-21	B Select	(XXXX)
22-25	C Select	(XXXX)
26-29	D Select	(XXXX)
30-33	1 Common	(XXXX)
34-37	2 Common	(XXXX)
38-41	3 Common	(XXXX)
42-45	4 Common	(XXXX)
46-49	5 Common	(XXXX)
50-53	Select Structural	(XXXX)
54-57	Construction	(XXXX)
58-61	Standard	(XXXX)
62-65	Utility	(XXXX)
66-69	Economy	(XXXX)
70-74	Total lumber volume	(XXXXX)

Trees from each of the four mill recovery studies are identified by a mill code number (card column number 1) and a separate color. The distribution of trees by mill studies is as follows:

Mill number	*Number of trees*
1	245
2	245
3	271
4	338
Total	1,099

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Laminated Root Rot of Douglas-fir in Western Oregon and Washington

By T. W. Childs

PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION
U.S. DEPARTMENT OF AGRICULTURE FOREST SERVICE
PORTLAND, OREGON

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Introduction

Laminated root rot, caused by the fungus *Poria weirii*, is damaging to many conifers in the Pacific Northwest, and especially to Douglas-fir *(Pseudotsuga menziesii)* west of the Cascade Range in Washington and Oregon. It attacks trees of all ages but is most destructive in stands from about 25 to 125 years old.

It is important primarily as a killer. Young infected trees seldom survive long enough for reduction of growth rate or extension of decay into the butt log to be of much consequence. In old-growth stands, where killing is slower, infection is less common, and decay usually extends only a few feet into butt logs and involves mostly the low-quality core.

This paper summarizes results obtained during the past 20 years from research still in progress.

Description

There are two forms or varieties of the fungus. One is common in the northern Rocky Mountains, principally on western redcedar *(Thuja plicata)*. The other is common in the Pacific Northwest, principally on hosts other than western redcedar. This paper is concerned exclusively with the latter form.

Early stages of *Poria weirii* decay appear as reddish-brown to brown streaks or broad bands on longitudinal sections of roots and trunks, and as circular, crescent-shaped, or irregular areas on cross sections (fig. 1*A*). In later stages of decay the annual rings tend to separate, and the wood contains numerous pockets about a fiftieth of an inch in diameter and a twentieth of an inch long. In final stages, wood breaks down into a loose, stringy mass and eventually may disintegrate completely, leaving butts hollow except for the branch bases, which remain sound (fig. 1*B*).

Figure 1.—*A*, Cross section of Douglas-fir base showing incipient and typical decay caused by *Poria weirii*; *B*, base of tree killed many years ago, showing persistent branch bases.

Thin, velvety layers or sparse tufts of brown fungus threads are usually present in crevices in decayed wood; and thin, brown crusts without pores sometimes form on surfaces of breaks. Sporophores are brown crusts containing hundreds of minute pores per square inch; they form in root crotches or on lower sides of down trees during late summer and early fall. By the next spring, they are mostly dead and moldy. Although fairly common in some years and localities, they are too inconspicuous to be useful in detecting the disease.

Some infected trees are "rot-thrown"—that is, blown down as a result of destruction of one or two of the main roots—before crown symptoms become conspicuous. Others slowly die standing, from killing of much of the root system or sometimes from girdling at the root collar.

Infection is occasionally found in single trees with no other visibly diseased ones nearby but usually occurs in patches or "centers" of infection (fig. 2), ranging from only a few feet in diameter to more than an acre in extent. Typical centers contain remains of trees, standing or more often down, that have been dead for different lengths of time. Some roots of down trees are broken transversely near the trunk (fig. 3*A*), exposing typical decay. Surviving trees in the interiors of centers are usually leaning or have thin or ragged crowns (fig. 3*B*), poor color, "distress crops" of abnormally small cones, or decreased terminal and lateral growth. Recent rot-throws as well as standing dying trees are often invaded by Douglas-fir bark beetles *(Dendroctonus pseudotsugae)*.

A

B

Figure 2.—*A*, Distant view of an infection center in a 70-year-old stand; *B*, an infection center in a 45-year-old stand.

In the interiors of infection centers, much or all of the forest cover may be destroyed over areas of several hundred square feet in pole stands and several thousand square feet in young-mature stands. In outer portions of centers, although forest cover is more or less intact, most of the trees are infected even though no symptoms may be visible; few of them will survive long enough to take advantage of the increase in growing space afforded by the death of their

A Figure 3.—*A*, Douglas-firs rot-thrown by *Poria weirii*, showing stubs of decayed roots; *B*, dead and dying trees in an infection center. B

neighbors. Opening of stands by this disease is a major cause, if not the principal one, of the retrogression from normality reported by Briegleb (1942).[1]

Occasional small centers are found where the disease seems to be no longer active, but irregular spread usually continues more or less indefinitely into the surrounding stand. Infection centers merge so gradually into the surrounding stand, or into nearby centers, that their numbers, dimensions, and distances between them can be determined only approximately.

Small centers are often overlooked, and centers of all sizes are often attributed to other causes. They are, however, readily distinguishable from stand openings caused by other pests and disturbances; and it is important to recognize them since they are usually indicative of continuing damage. In blowdowns and groups of beetle-kills where root rot is not a factor, most of the killing will be found to have occurred simultaneously or nearly so, and roots are mostly sound. Where root rot is caused by *Armillaria mellea*, white to cream-colored mycelial fans[2] are present between bark and wood at bases of dead and dying trees. Less common root-rotting fungi, such as *Polyporus tomentosus* and *Fomes annosus*, cause decay differing in appearance from that caused by *Poria weirii*.

Range and Hosts

Laminated root rot is known to occur from central British Columbia to southern Oregon and eastward into northern Idaho. It is common from sea level to well above the upper limits of commercial forests, on good to poor sites, and on many kinds of soils from deep loams to gravels.

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[1] Names and dates in parentheses refer to "Literature Cited," p. 26.

[2] These fans are sometimes present in Poria-killed trees, saprophytically invaded by Armillaria, but in such instances they are not accompanied by the copious resinosis characteristic of parasitic attack.

Douglas-fir, Pacific silver fir (*Abies amabilis*), lowland white fir (*A. grandis*), and mountain hemlock (*Tsuga mertensiana*) are the most consistently susceptible hosts. Infection centers similar to those in Douglas-fir stands often occur in pure stands of silver fir and in subalpine stands predominantly composed of mountain hemlock.

Western larch (*Larix occidentalis*), alpine fir (*Abies lasiocarpa*), white and lodgepole pines (*Pinus monticola* and *P. contorta*), and Sitka and Engelmann spruces (*Picea sitchensis* and *P. engelmannii*) are attacked when associated with more susceptible species. Ponderosa pine (*P. ponderosa*) and western redcedar are rarely attacked. One probable infection, not verified by culture, has been observed in incense-cedar (*Libocedrus decurrens*).

Western hemlock (*Tsuga heterophylla*) appears to be about as susceptible as any other host where mixed with Douglas-fir of the same age, but is rarely infected in pure stands, and often remains healthy where present as a younger understory in infected Douglas-fir stands. Table 1 summarizes data from a small plot where a hemlock understory had been released during the past century by gradual destruction of the old-growth Douglas-fir overstory by *Poria weirii*. The one hemlock found infected here had grown in immediate contact with a recently rot-thrown Douglas-fir. Similar results were obtained from two plots under similar conditions in the Cascade Range of Washington.[3] Table 2 summarizes data from 20 years of observations on two small plots established in a stand about 50 years old.

Table 1.—Incidence of *Poria weirii* on Douglas-fir and western hemlock on a 0.9-acre plot in the Oregon Coast Ranges

Tree species and condition	D.b.h. class (inches)					
	3-10	10-20	20-30	30-40	40-50	50-60
	Numbers of trees					
Killed by *P. weirii*:						
Douglas-fir	10	24	6	3	1	3
Western hemlock	0	0	0	0	0	0
Living — total:						
Douglas-fir	9	24	13	1	0	0
Western hemlock	28	53	23	5	0	0
Living — infected:[1]						
Douglas-fir	1	3	1	1	0	0
Western hemlock	0	1	0	0	0	0

[1] As indicated by discoloration or decay in increment cores. A few infected trees were undoubtedly diagnosed as uninfected.

[3] Most of the data from all three of these plots were lost in a Station tragedy.

Table 2.—Incidence of *Poria weirii* on Douglas-fir and western hemlock on 3.4 acres of plots in the Oregon Cascade Range

Tree species and condition	D.b.h. class (inches)		
	2-6	6-10	>10
	Numbers of trees		
Killed by *P. weirii* before plot establishment:			
Douglas-fir	23	40	104
Western hemlock	0	0	0
Living when plots were established:			
Douglas-fir	219	75	289
Western hemlock	119	20	0
Killed by *P. weirii* after plot establishment:			
Douglas-fir	23	14	89
Western hemlock	0	0	0

Previous Research

Murrill (1914) described and named the fungus from a collection of the Rocky Mountain form on western redcedar. Overholts (1931) and Baxter (1934, 1953) also published mycological descriptions and compared the fungus with other brown Porias. Buckland, Molnar, and Wallis (1954) discussed differences between the Rocky Mountain and Pacific Northwest forms.

Mounce, Bier, and Nobles (1940) reported the fungus on Douglas-fir and western hemlock on Vancouver Island. They also described cultural characters, incipient and typical decay, and symptoms of the disease. Bier and Buckland (1947) reported extensive damage to young Douglas-fir stands and described spread around infection centers. Buchanan (1948) found infection in 15- to 20-year-old reproduction associated with infected old-growth stumps. In a heavy windthrow following thinning of a stand where infection was common, Wallis (1954) found that most of the down trees were infected.

Results of several important studies were reported by Buckland, Molnar, and Wallis (1954), Wallis and Buckland (1955), Buckland and Wallis (1956), and Wallis and Reynolds (1962, 1965). They found that the fungus survives less than four months in wood blocks buried in unsterilized forest soil, but that it can survive for more than 50 years in dead roots of infected trees, from which it may spread to living trees; that spread from one tree to another can occur through intact bark of uninjured roots; that mycelium grows profusely on western hemlock roots and invades them readily; and that bark beetle populations increase in infection centers. They conclude that no Douglas-firs are immune, although

some appear less susceptible than others; that species mixtures, thinning, trenching, and burning offer little promise of control; and that the disease will probably increase in severity from one rotation to the next.

From clone studies and other evidence, Childs (1963) concludes that root grafts are not necessary for passage of infection from tree to tree, that the fungus can survive in dead roots for nearly 100 years, and that the great majority of infection centers in present-day stands are attributable to vegetative persistence of the fungus in centers that originated in previous stands. Nelson (1964) found that the fungus survived far longer in buried wood blocks in which zone lines formed than in buried blocks without zone lines, and that soil fungi antagonistic to *Poria weirii* were much more common in the latter than in the former.

Surveys and Plot Studies

Surveys consisted of 20- to 100-percent cruises of more than 6,000 acres, of which more that 2,500 acres were examined. This acreage was mostly in sapling to young-mature Douglas-fir types but included some mixed-conifer types both with and without Douglas-fir. The following data were recorded by 2- by 2-chain sampling units: forest type and stocking, size and location of infection centers, and estimated percentage of stand destroyed. Cruise data were occasionally checked by counts of trees living and killed on systematically located small plots, and were supplemented by intensive examination of temporary plots, including some old-growth type, on areas of special interest.

These surveys were not designed to provide a reliable estimate of the regionwide prevalence of the disease, but they yielded considerable information on patterns of infection occurrence.

Surveys referred to most frequently in this paper were as follows:

Snow Creek—244 acres examined in a pure, 27-year-old stand of planted Douglas-fir in eastern Clallam County, Washington, elevation 1,300 feet, site quality III.

Jimmycomelately—179 acres examined in a 70-year-old stand, partly pure Douglas-fir and partly mixed conifers, a few miles north of Snow Creek, elevation 600 to 1,600 feet, site quality IV.

Guler Road—A 115-year-old stand in Skamania County, Washington. Eastern part: 704 acres examined, mostly in mixed conifers, elevation 2,500 to 3,400 feet, site quality IV. Northwestern part: 128 acres examined, partly in pure Douglas-fir and partly in mixed conifers, elevation 2,600 to 2,800 feet, site quality III. Southwestern part: 672 acres examined, pure Douglas-fir, elevation 2,500 to 2,800 feet, site quality III.

To determine rates of damage, we established twenty 10-acre plots in large-sapling to young-mature Douglas-fir stands ranging from very lightly to very heavily infected. Plot locations were determined largely by convenience of access, freedom from roads or other complicating features, and reasonable prospects of freedom from disturbance for a few decades. Plots were fairly representative of the much more extensive stands in which they were situated, except that infection on some of them was more common than in surrounding stands.

Plots were subdivided into 2- by 2-chain blocks. On each block, living trees were tallied by species and d.b.h., and trees killed by Poria were sketch-mapped and tallied by species, d.b.h., and estimated number of years since death. In subsequent examinations, mortality (except suppression in sapling and small-pole stands) was tallied by species, d.b.h., and cause of death, and trees killed by Poria were sketch-mapped. Brief descriptions of 11 of these plots (excluding the most lightly and the most heavily infected and those disturbed by cutting) are given under "Rates of damage."

On a few smaller plots, all living trees and trees that had been killed by Poria were given numbers, stem-mapped by plane table, and recorded by species, d.b.h., and symptoms of disease (or estimated years since death). Deaths from Poria and symptom changes were recorded in subsequent examinations.

Killing by the disease occurs so irregularly that many years of records from numerous plots will be required for accurate determinations of damage rates under different intensities of infection. Records now available provide a basis for only rough estimates.

Since *Poria weirii* appears unable to compete with other fungi in trees where it did not become established prior to death, all dead trees in which it was found were tallied as killed by Poria. Although probably not the immediate cause of death in every instance, it would almost always have killed within a few years. In any event, the slight overestimation of disease impact that may have resulted from errors in assigning causes of death was more than compensated by the relatively small basal areas of killed trees as compared to what their basal areas would have been had they survived until the stand was measured.

Patterns of Infection Occurrence

Poria weirii is a native of the Douglas-fir type. It is just as "normal" an inhabitant as vine maple, but is much more irregularly distributed. On the 51 quarter sections partly or entirely examined during the surveys, impact of the disease varied as follows:

Percent of stand destroyed	Number of quarter sections
Less than 0.1	10
0.1 - 2.0	19
2.1 - 4.0	6
4.1 - 6.0	7
6.1 - 8.0	3
8.1 - 10.0	2
More than 10.0	4

The disease varies greatly in abundance even over short distances in otherwise uniform stands. Like infected trees, infection centers tend to be associated rather than randomly distributed. Infection distribution shown in figures 4 and 5 is characteristic except that infection was more than ordinarily common on these two areas.

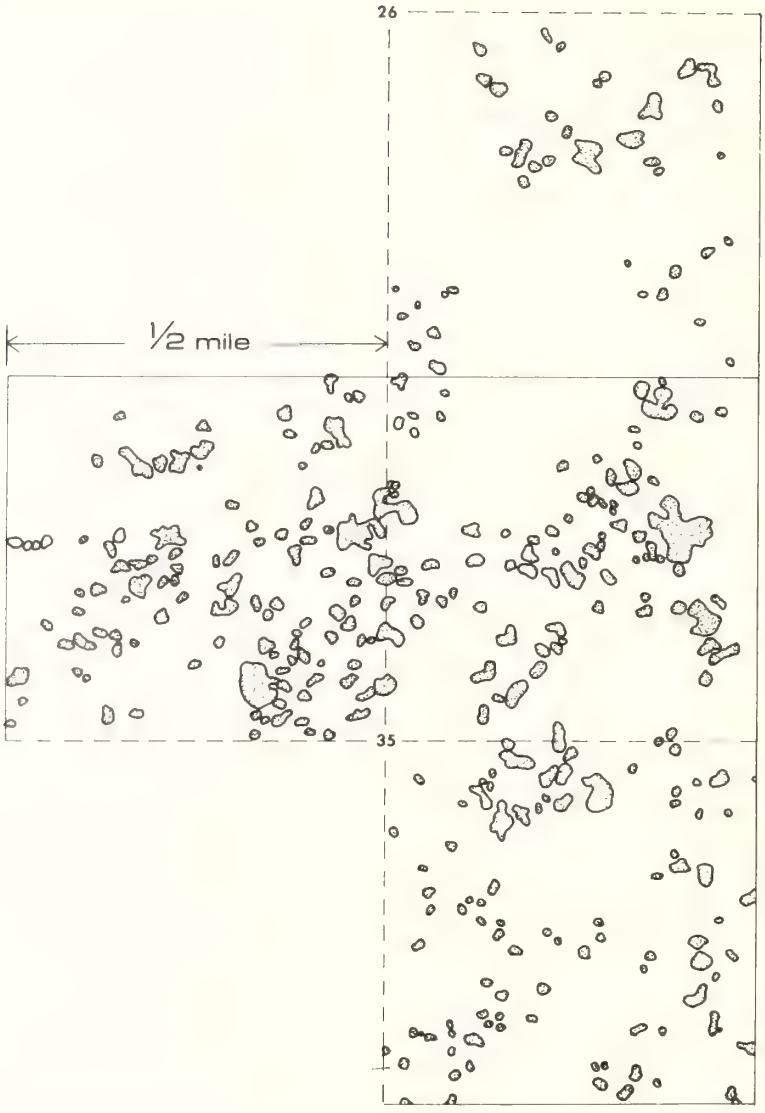


Figure 4.—Infection centers in a pure, well-stocked, and even-aged stand of young-mature Douglas-fir (southwestern part of Guler Road survey). Shaded areas are infection centers or aggregates of closely associated centers.

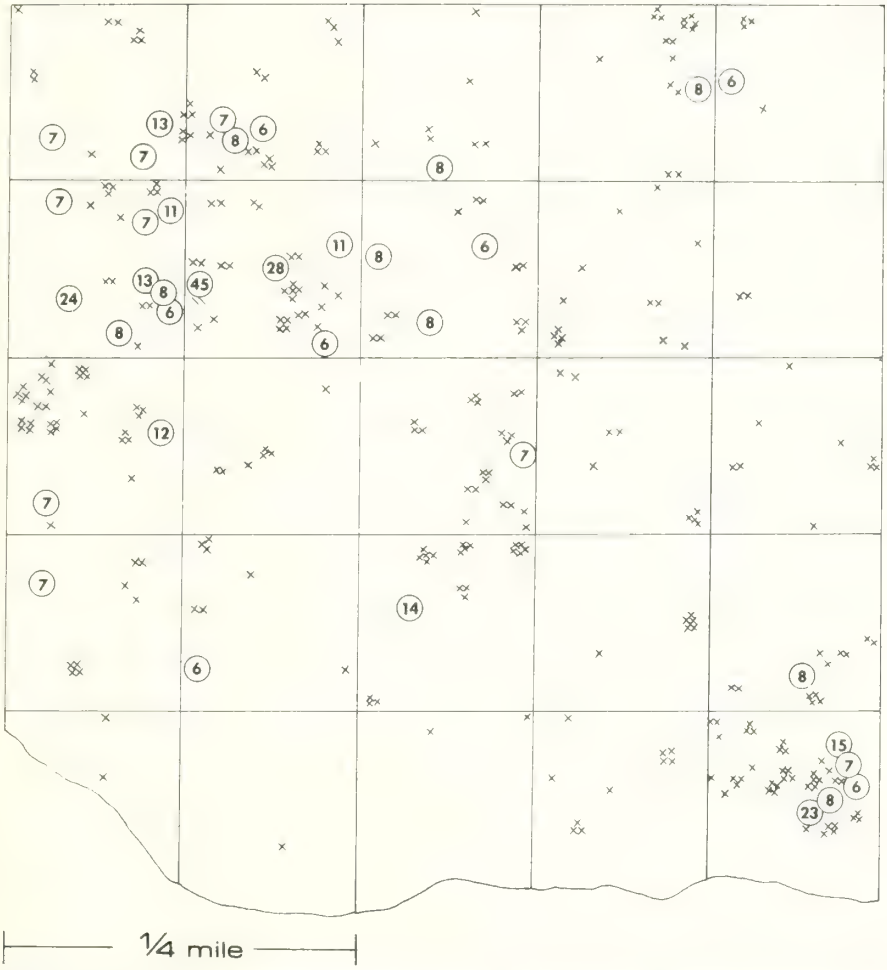


Figure 5.—Infection in a densely stocked plantation of 27-year-old Douglas-fir (Snow Creek survey). Crosses are individual killed trees; circled numerals are numbers of killed trees in groups of more than five.

On the quarter sections shown in figure 4, and on an adjacent quarter section where the stand was also pure Douglas-fir, incidence of the disease was as follows:

Locality	Percent of 2- by 2-chain blocks with infection	Percent of stand destroyed
SW ¼ sect. 26	9	Trace
SE ¼ sect. 26	22	2
NW ¼ sect. 35	55	6
NE ¼ sect. 35	40	6
SE ¼ sect. 35	36	4

In the 70-year-old stand at Jimmycomelately and on the remainder of the Guler Road survey, where stands were less uniform and included considerable proportions of mixed-conifer types, infection incidence by quarter sections ranged as follows:

Locality	Percentage of 2- by 2-chain blocks with infection	Percentage of stands destroyed
Jimmycomelately	56 to 91	6 to 14
Guler Road	0 to 28	0 to 5

Differences are even greater, of course, between smaller subdivisions of land. On 10-acre subdivisions of the area shown in figure 4, percentages of 2- by 2-chain blocks infected ranged from 0 to 76, and percentages of stand destroyed ranged from 0 to 18.

Differences in incidence of infection may be either a result or a cause of forest type differences. In the examples in table 3, types at Guler Road were probably much the same in the early life of the stand as at present. Here, the common occurrence of infection on blocks of "other conifers only" was attributable to high susceptibility of Pacific silver fir, which was especially abundant on section 30, where it formed occasional small pure stands. At Jimmycomelately, western hemlocks and western redcedars were common but usually too small to affect type designations except where death of Douglas-firs had released them. The following regressions (all significant at the 1-percent level) were obtained from 344 sample plots, each one-twentieth of an acre in extent, in this stand:

Dependent variable	Change in dependent variable for each increase of 1 percent in Douglas-fir basal area killed by Poria
	(Percent)
Basal area of living Douglas-fir	-0.7
Basal area of living "other conifers"	+1.3
Basal area of living total conifers	-.4
Number of "other conifers," 4-inch d.b.h. and larger	+.8

At Jimmycomelately, many blocks of "other conifers only" had originally contained Douglas-firs later killed by Poria. At both Guler Road and Jimmycomelately, most infection on blocks of mixed conifers was of Douglas-fir or true firs.

Present differences in infection may be correlated with past differences in infection or in type. Vegetational changes associated with infection centers in preceding stands may have influenced the proportion of highly susceptible species in present stands—for example, by affecting the intensity of terminal fires. As will be shown later, infection centers persist from one forest generation to the next and consequently are most likely to be common where stands of highly susceptible hosts have occurred in uninterrupted succession.

Complex relationships undoubtedly also exist between the disease and stand density, but small dead trees disappear so rapidly that original densities could not be determined. Here, too, conditions in present stands are no doubt

Table 3.—Examples of *Poria weirii* occurrence in different forest types[1]

Locality	Total blocks				Blocks with Poria			
	D[2]	D + others[3]	Others + D	Others only	D	D + others	Others + D	Others only
	Number				*Percent*			
Guler Road:								
E 1/2 of sect. 30	331	228	40	127	5	12	30	46
Sects. 19, 20, and 29	207	565	116	55	3	2	1	2
Remainder	86	163	39	45	16	18	10	7
Jimmycomelately	319	100	20	4	74	79	85	25

[1]Data are from only those quarter sections where both pure Douglas-fir and other coniferous types were present.

[2]Douglas-fir.

[3]Other conifers.

partly attributable to those in preceding stands. Interaction of *Poria weirii* and its environment is a fertile field for hypotheses but is unlikely to yield many definite conclusions until a larger factual basis is available.

Number of centers, as well as their distribution and area, is important because further damage will result largely from spread into the surrounding stand and will consequently be greater from numerous small centers than from a few larger ones with more total area but less periphery. On the 640 acres of the young-mature stand at Guler Road shown in figure 4, there were 342 centers of the disease averaging 0.1 acre in size, and about 4.4 percent of the stand had been destroyed. On the 244 acres of the 27-year-old plantation at Snow Creek shown in figure 5, there were 199 centers averaging less than 0.01 acre in size (often consisting of only one or two dead trees), and less than 1 percent of the stand had been destroyed, but presence of infection at so many places will probably result in losses per acre exceeding those at Guler Road before the plantation reaches commercial maturity.

Although control of laminated root rot is not yet possible, losses can often be reduced if incidence of the disease in the various parts of the stand is known. Since the disease is so irregularly distributed, ground surveys accurate enough to be useful are too expensive to be generally practical at this time, even when made in conjunction with surveys for other purposes. Medium-sized to large infection centers and concentrations of small ones were easily visible on 1:12,000 aerial photos of the area shown in figure 4; but even on 1:3,000 photos they could not be distinguished from old beetle-kill areas, brush patches, and other stand openings not indicative of continuing losses. Until better methods become available, information needed for good management must be obtained by careful observation, at every opportunity, of disease conditions in all parts of the stand.

Persistence and Spread

Although *Poria weirii* produces great numbers of viable spores, it appears unable to establish itself in dead material in competition with other fungi. Examinations of thinnings, some more than 30 years old, have disclosed no instance of stump infection by spores. Only one doubtful instance has been observed of infection of Douglas-fir through a trunk wound, and very few infections through wounds have been found in hundreds of trees of other species dissected in decay studies.[4] From studies of clones of the fungus it is evident that the great majority of infection centers now existing are "holdovers"—that is, results of vegetative persistence and spread of infections that started from spores in stands preceding the present ones.

Tests with hundreds of cultures of *Poria weirii* have shown that, if moisture and nutrients are adequate for vigorous growth until contact between mycelia is well established, all isolates of a clone are compatible in culture with all other isolates of that clone and antagonistic[5] to all isolates of other clones (fig. 6). Since *P. weirii* does not produce asexual spores, isolation of the same clone from different trees is proof that spread of the fungus between them has not been by spores. Transfer of vegetative inoculum by insects or other vectors is possible;

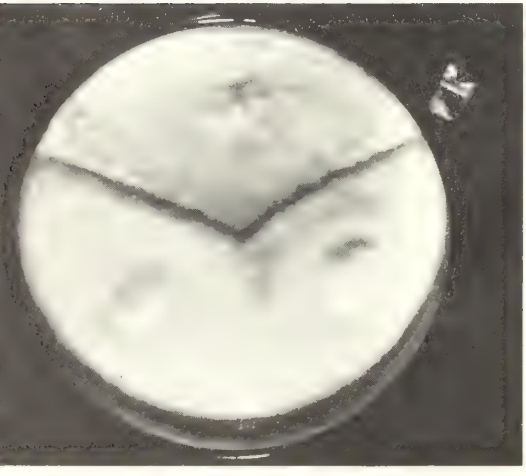


Figure 6.—Three isolates of *Poria weirii* growing in the same petri dish. The two isolates that have grown together with no indication of antagonism are of the same clone, from trees about 65 feet apart; the isolate that is separated from the other two by a narrow dark zone is of another clone, from a tree about 375 feet from the first two.

[4] Buckland, Foster, and Nordin (1949) found no *Poria weirii* in 719 dissected Pacific silver firs and only two infections through wounds (six others from undetermined entry points) in 963 western hemlocks. Wright and Isaac (1956) found four infections associated with wounds in 1,030 western hemlocks and none in 126 Sitka spruces and 62 true firs.

[5] Buckland, Molnar, and Wallis (1954) found no antagonism between isolates from Douglas-fir but do not state whether their isolates were from closely associated or widely separated trees.

but studies of mycelial growth on roots (Wallis and Reynolds 1962, 1965), of the close association of diseased living trees with killed trees (Childs 1963), and of orientation of decay on tops of stumps (to be discussed later) leave little doubt that clonal spread is almost always, if not invariably, by vegetative growth of the fungus.

Tests of isolates from 152 infection centers, on 10 of the 10-acre damage plots in six stands, showed that 130 of the centers were caused by only 36 clones, each of which was isolated from two or more centers. Occurrence of the same clone in distinctly different centers cannot have resulted from vegetative spread during the life of the present stand, because centers of the same clone are separated by zones of healthy forest often more than 100 feet wide. Examples of clones occurring in more than one center are shown in figure 7.

Of the 22 centers occupied by clones not found elsewhere, probably few if any originated from spore infections in present stands. Ten of the 22 were in corner blocks of plots, and only four were more than 2 chains from plot edges, so several of them undoubtedly had clones in common with centers off the plots (or with plot centers from which no cultures were obtained). The shape of some suggests formation by fusion of smaller centers. And since 10 of the 36 "multiple-center" clones were found in only two centers each, and 11 in only three centers each, it can reasonably be assumed that several "holdover" clones have appeared in only one center each.

Infection from residues of the previous stand at more than one point within a center is probably fairly common, but most spread is between trees of the present generation. This is evident not only from the close association of recently killed trees with older kills (fig. 8), and the rapid decrease in percentage of living trees infected as distance from killed trees increases (Childs 1963), but also from the tendency of decay in living infected trees to be oriented toward the nearest killed tree. On a 16-acre clearcut area at Guler Road, 149 stumps with unsymmetrical decay caused by *Poria weirii* were found within 50 feet of killed trees; 101 of these 149 had the most extensive decay within 45° of the direction of the nearest killed tree, and only 20 within 45° of the opposite direction. Since some trees undoubtedly become infected by indirect routes, some from nearby but not the nearest killed trees, and some from infected trees not yet killed, it is evident that most infections result from tree-to-tree spread.

Rate of vegetative spread from tree to tree cannot be determined from data now available, since instances of apparently rapid spread may or may not be results of new infections from residues of the previous stand and since groups of progressively infected trees are often rot-thrown simultaneously or may die almost simultaneously when subjected to unusual moisture stress. Spread rate probably varies widely in response to differences in root network patterns and other vegetational and soil factors. Figure 8 shows that spread is far from uniform around centers even where susceptible hosts are about equally numerous in all directions.

The fungus grows fairly rapidly along root surfaces (Wallis and Reynolds 1962) but increase in average radius of infection centers appears to be less than a foot per year. Nevertheless, long-continued vegetative spread (in some instances probably during several forest generations) often distributes infection over considerable distances (table 4).

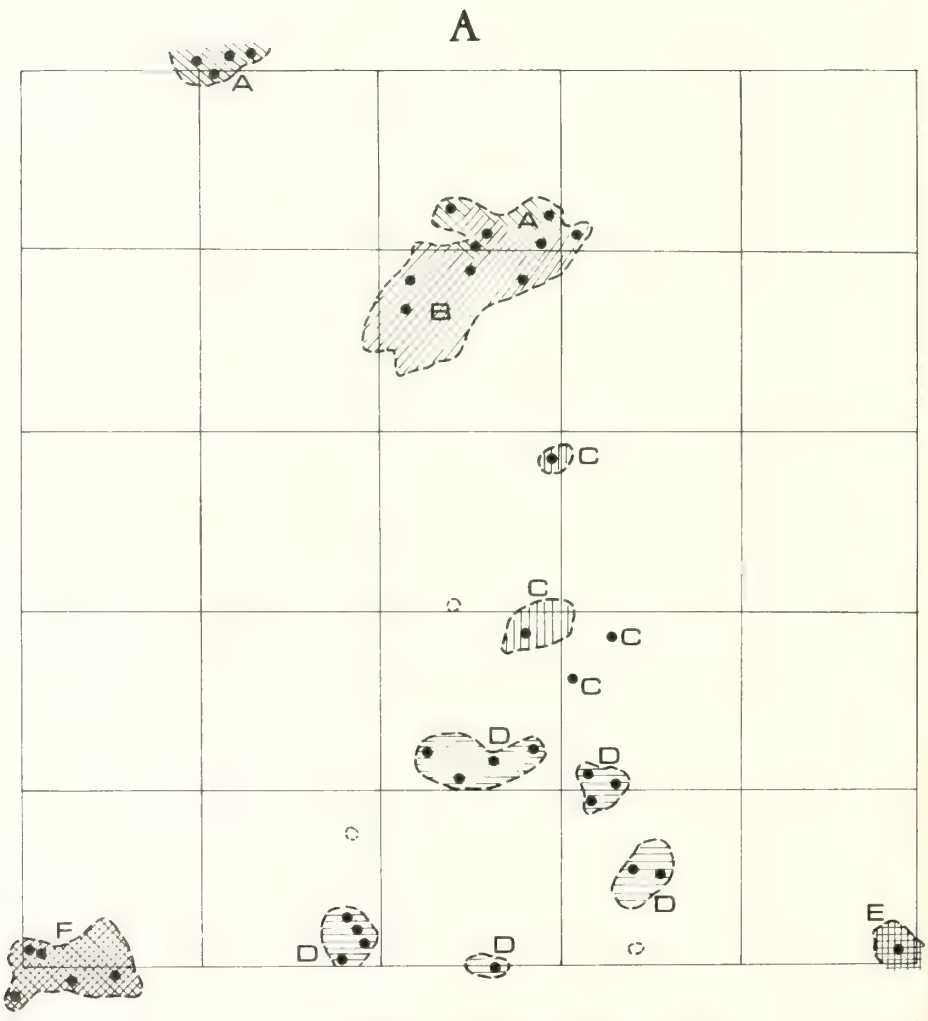
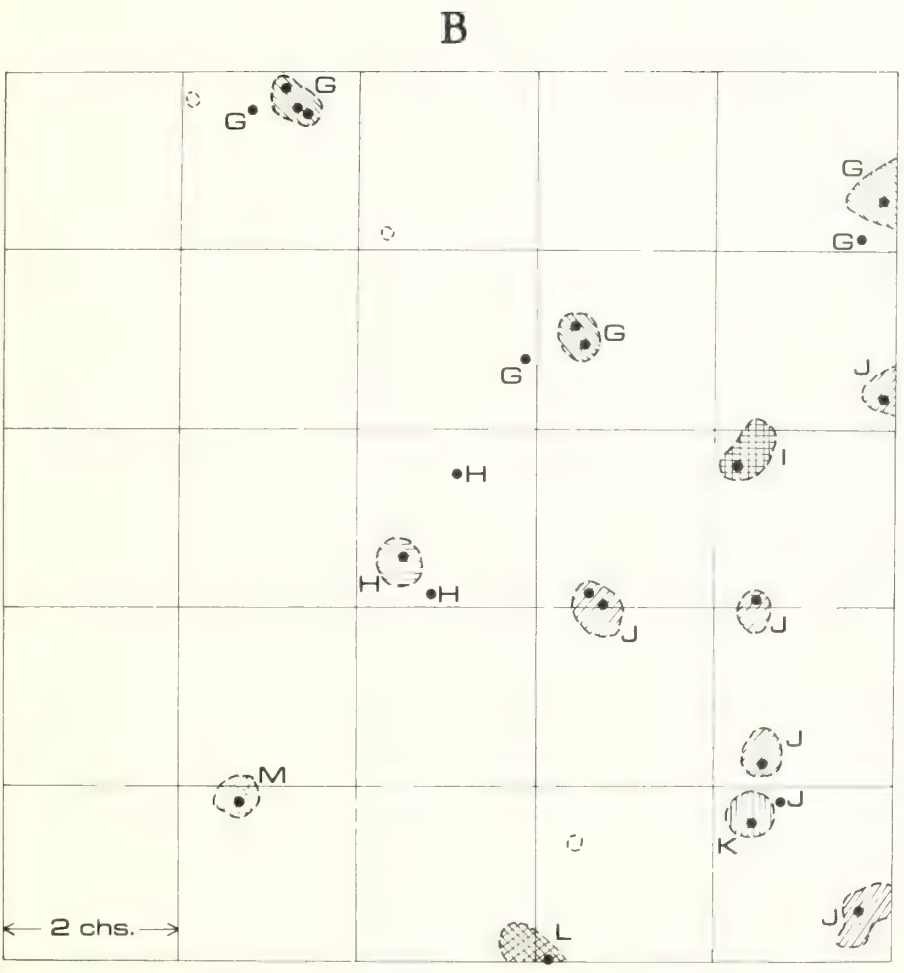


Figure 7.—Clones and infection centers on: *A*, Clemons south plot and *B*, Snow Creek east plot. Broken lines are approximate boundaries of infection centers. Letters are



clone designations. Solid circles indicate trees from which cultures were obtained. Unshaded centers are those from which no cultures were obtained.

A

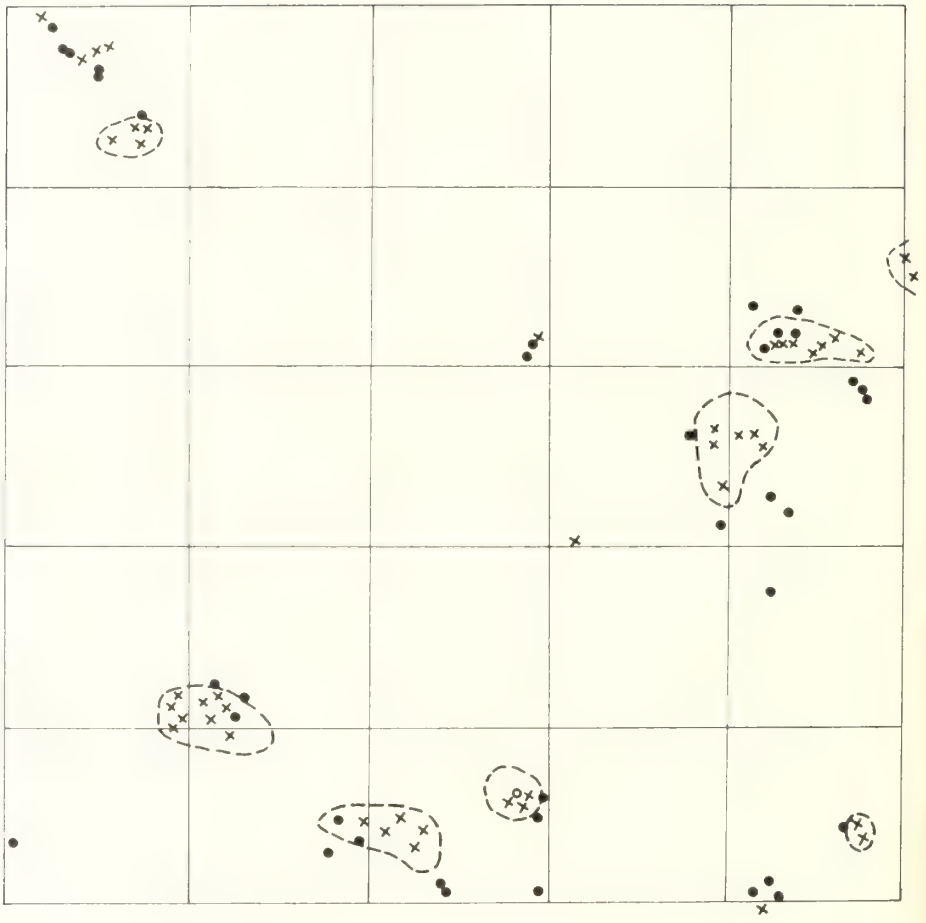
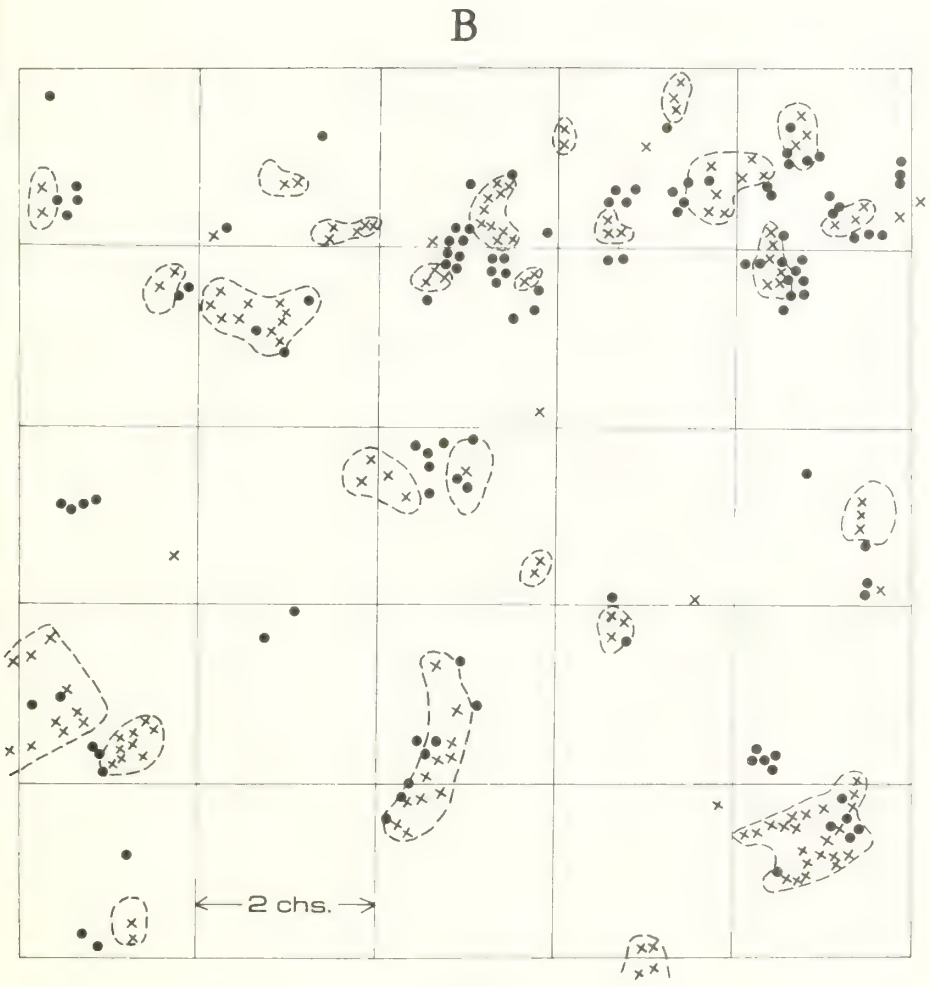


Figure 8.—Association of recently killed trees with previously killed trees at: *A*, River Road plot and *B*, Martha Flat plot. Circles are trees killed since plot establishment (11



years ago at River Road and 16 at Martha Flat). Crosses are trees killed before plot establishment. Broken lines are approximate boundaries of infection centers when plots were established.

Table 4.—Maximum distances between sources of cultures of single clones found in more than one infection center

Plot	Age of stand	Number of centers in which the clone was found						
		2	3	4	5	6	7	8
	Years	*Feet*						
Snow Creek east	28		80	480		390		
Snow Creek west	28		160		330			
Elma	30	290						
Martha Flat	42	70	230	320	140			340
			90					
Martha Creek	43	110	100			350	390	
River Road	50	120	110					
		210	150					
		80	160					
Clemons south	60	280		160	240			
Clemons north	60	100	100	300	460			
			130					
Mouse Creek south	110		400	230		370		
Mouse Creek north	110	520		430				
		220						

Because of its persistence in underground inoculum, *Poria weirii* will probably become more damaging in stands managed intensively—where the new forest generation is established immediately after removal of the old—than in unmanaged stands, where restocking is often delayed.

Damage

In sapling and pole stands, losses of actual volumes are seldom great, and damage consists almost entirely of reduction of productivity through conversion of numerous small areas into brush patches or groups of younger trees of less susceptible species. When changes of the latter kind occur early in the life of the stand and on sites permitting good growth of the less susceptible species, damage may be slight. But on most Douglas-fir sites, especially when the type change is long delayed, productivity is reduced even if forest cover is maintained almost continuously.

The best measure of past damage and indicator of future damage would be numbers and sizes of infection centers if it were practicable to determine these with sufficient accuracy. Percentage of trees killed is only roughly indicative of infection severity, since remains of small killed trees soon disintegrate or are hidden by litter; this percentage is also distorted by irregularities in stand density and normal decrease in numbers of trees as stands become older. Basal area percentage underestimates impact of the disease, since basal areas of trees killed several years ago do not adequately represent, in proportion to present basal areas of surviving trees, their potential contribution to yield. In young stands, the

most important question is how much damage is to be expected before commercial maturity is reached, rather than how much has already occurred; and percentage of either trees or basal areas killed is as good a basis as is now available for approximate predictions.

In young-mature stands most of the damage may have already occurred, but characteristic infection centers are common and substantial losses often continue.

At Guler Road, for example, the disease appeared to have become inactive in some of the smaller centers but was still causing damage in the remainder. On 16 acres of a clearcut area (near the center of fig. 4) there were 1,455 Douglas-firs, living or beetle-killed within the past year, with a basal area of 3,317 square feet. *Poria weirii* had killed 242 trees (14 percent of total living and killed) with a basal area of 479 square feet (13 percent). About half of the killing by Poria had occurred within the past decade. Of the living and recently beetle-killed trees, 279 (19 percent) with basal area of 677 square feet (20 percent) showed *P. weirii* decay on the stump surface and would probably have been killed within the next two or three decades.

Distribution of the disease on this area (fig. 9) suggests that most of the *Poria weirii* clones present had originally appeared in two or more centers each,

Figure 9.—Distribution of clones of *Poria weirii* and infected trees on 16 acres of a clearcut area. Crosses are trees killed by *P. weirii;* circles are infected living (including recently beetle-killed) trees; letters designate the 10 clones responsible for the damage; dotted lines are approximate boundaries of clone areas.

separated by zones of healthy forest, and that the centers expanded toward each other until they became more or less continuous.

Severe damage by bark beetles in this locality may also have resulted indirectly from the widespread infection by *Poria weirii*. Ordinarily, a large proportion of Douglas-fir bark beetle attacks occur in trees weakened by root diseases. In 1952-53, a period exceptionally favorable for beetles, only 8 percent of trees with Poria infection (as indicated by decay on the stump surface) were killed by beetles on the area shown in figure 9, while 15 percent of the apparently uninfected trees were killed, but over an area of several square miles the killing was obviously concentrated on and near the areas of heaviest infection. This substantiates previous observations that root rot centers help to maintain beetle populations at moderate levels during ordinary years and serve as sources of infestation of surrounding healthy stands when conditions permit beetles to invade uninfected trees.

Larger killed trees in young-mature stands retain some salvable volume for several years, but much of their volume and most of their quality is in the sapwood, which deteriorates rapidly after death.

Even where infection is abundant, cull from *Poria weirii* decay in living trees is of relatively little importance. In a 110-year-old stand, where infection was heavy on 3 acres of the logged area and light to moderate on the remainder, such cull did not exceed 0.5 percent:

	Area A	Area B	Area C
Acres logged	3	25	22
Percent of live stand cut	100	25	15
Percent of total stand killed by Poria	14	4	2
Living trees felled:			
Total number	147	531	359
With Poria decay on stumps:			
Percent by number	24	13	7
Percent by volume	26	12	5
Percent of total felled volume cull from Poria decay	.4	.5	.1

Heaviest losses here were from windthrow subsequent to logging. Only 23 trees went down during the first winter after the cutting, but during the second winter nearly half of the remaining trees on area *B* and about three-fourths of those on area *C* were windthrown.

In old-growth stands, characteristic infection centers are seldom common even where infection is present. For example, no rot-thrown trees could be found on the clearcut area summarized in table 5, and no indications of the disease were visible in the contiguous uncut stand. However, the presence of more hemlock than is usual in this locality may have resulted from killing of some of the Douglas-fir when the stand was young.

When active infection centers do occur in old stands, they are of special concern because of the value of the timber involved. On one center covering a little more than an acre in a 225-year-old stand, approximately 35,000 board feet of Douglas-fir had been killed, 60,000 showed Poria decay on stump surfaces and would presumably have been lost if harvest had been long

Table 5.—Occurrence of *Poria weirii* infection in an old-growth stand with no external indications of infection

Tree species and condition	D.b.h. class (inches)				
	21-30	31-40	41-50	51-60	Total
	Numbers of trees				
Douglas-fir—living trees:					
Total	7	13	22	18	60
Infected[1]	0	2	9	5	16
Douglas-fir—snags:					
Total	3	7	6	2	18
Infected[1]	1	3	1	1	6
Western hemlock—living trees:					
Total	53	38	20	4	115
Infected[1]	4	4	0	1	9
Western hemlock—snags:					
Total	2	1	0	0	3
Infected[1]	1	0	—	—	1

[1] As indicated by decay on stump surface.

postponed, and only 52,000 appeared to be free from infection.

In the most severely damaged old stand examined, data were taken from thirteen 2.4-acre sample plots scattered over several thousand acres. On these plots there were 1,193 living Douglas-firs (basal area 9,182 square feet) and 342 living western hemlocks (basal area 908 square feet). *Poria weirii* had killed 231 Douglas-firs and three hemlocks, or 16 percent of the total living and killed Douglas-firs (12 percent of the basal area[6]) and 1 percent of the hemlocks. The plots were located where infection was obviously abundant, but local foresters estimated average current losses from the disease at nearly 200 board feet per acre per year over an area of about 100,000 acres.

Douglas-fir heartwood decays rather slowly, and large dead trees may remain merchantable for many years, especially if lying on moist ground in shaded situations. They steadily lose value, however, partly from continued decay by *Poria weirii* in butts but principally from decay of the high-quality sapwood and outer heartwood by other fungi. In the stand mentioned in the preceding paragraph, values were being lost so rapidly that logging plans were drastically revised to give priority to the more severely infected areas.

[6] In this instance, the smaller average basal area of killed trees is probably due less to continued growth by surviving trees than to underestimation of original diameters of down trees.

Much of the killed volume can often be salvaged where damage is concentrated. Volumes in occasional trees killed in old-growth stands may be greater in the aggregate and are more difficult to salvage. But usually, by the time the stand has reached the old-growth stage, most of the damage has already occurred, through destruction of immature growing stock and conversion of parts of the stand to brush patches or groups of younger trees of less susceptible species.

Rates of damage cannot be determined accurately from the meager data now available, but rough estimates are possible. Theoretical reconstructions of stands as they existed in past years indicate that damage in young stands doubles about every 15 years (Childs 1960), and records from several years of observations on permanent plots substantiate this conclusion. But ratios of current damage to total damage usually decrease after a few decades.

Table 6 summarizes 1,190 acre-years of records from 11 plots (including five pairs, each separated by several hundred feet) representative of six practically pure Douglas-fir stands. Although these stands differ considerably in site quality and other characteristics, total damage to date of plot establishment (columns 8 and 9) is shown to increase fairly consistently with increasing age. Except on the oldest plots, current annual damage (column 12) also increases with age, largely if not entirely because of increased numbers and peripheries of infection centers. Ratio of current to past damage (column 13) decreases with increasing stand age, as new centers appear less frequently and as enlargement of older centers reduces their periphery-area ratio.

Current damage rates in table 6 may, at first glance, appear too small to be of much consequence, but it must be remembered that these are *annual* losses and that, since most of the stand in infection centers is destroyed, percentage of productive acreage lost is approximately equal to percentage of basal area lost. For example, annual loss of 0.12 percent of basal area (average for the three youngest stands in table 6) over a 60-year period will reduce final yield by about 7 percent. It is estimated that loss from *Poria weirii* in western Oregon and Washington amounts to 32 million cubic feet annually (Childs and Shea 1967); most of this is loss of potential yield from young Douglas-fir stands.

Laminated root rot is not a catastrophic disease and usually not very spectacular. It occasionally causes heavy losses of merchantable timber, but its principal effect is its gradual attrition of growing stock by innumerable small centers of infection.

Further Research Needed

Although dissemination of *Poria weirii* by spores should not be entirely ignored, the obvious major problem is how to retard spread of established infection centers and prevent their persistence from one rotation to the next. Existence of natural controls is shown by the common occurrence of belts of healthy forest between centers inhabited by the same clone of the fungus, and by occasional failure of the disease to continue its spread from small centers. Evidence now available suggests that the principal natural controls are hyperparasitic or otherwise antagonistic soil micro-organisms. Accordingly, studies most likely to yield results useful in forest management appear to be

Table 6.—Total and current damage by *Poria weirii* on 11 lightly to moderately infected plots

Plot[1]	Length of record	Site quality	Stand age[2]	Average d.b.h.[2]	Average stand per acre[2]		Killed by Poria				Current annual loss of basal area from Poria	
							Before plot establishment		After plot establishment			
					Trees	Basal area	Trees	Basal area	Trees	Basal area	Total average[3]	For each 1 percent killed before plot establishment[4]
1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.
	Years		*Years*	*Inches*	*No.*	*Sq. ft.*			*Percent*			
Snow Creek west	11	III	28	7.6	547	182	0.47	0.34	0.51	0.81	0.074	0.214
Snow Creek east	11	III	28	7.6	529	182	.83	.50	.72	1.03	.094	.186
Bare Mountain south	6	III	30	8.0	284	116	.66	.46	.25	.16	.026	.057
Bare Mountain north	5	III	30	9.5	214	127	1.02	.97	.70	.65	.130	.135
Martha Flat	16	IV	42	6.5	501	142	2.40	1.79	2.42	2.54	.159	.089
Martha Creek	14	IV	43	6.7	539	155	4.31	3.64	2.67	3.56	.255	.070
River Road	11	II	50	17.7	118	217	3.29	2.77	3.32	3.48	.316	.114
Clemons south	9	II	60	15.3	138	197	6.14	3.57	2.18	2.06	.229	.064
Clemons north	9	II	60	16.7	96	166	6.21	3.96	1.45	1.11	.123	.031
Mouse Creek south	14	IV	110	19.0	112	236	4.91	3.94	1.78	1.78	.127	.032
Mouse Creek north	13	IV	110	16.6	156	247	5.74	4.71	1.67	1.71	.132	.028

[1] River Road plot is in Clackamas County, Oregon. Others are in Clallam, Grays Harbor, and Skamania Counties, Washington.

[2] At time of plot establishment. Douglas-firs only.

[3] Column 11 divided by column 2.

[4] Column 12 divided by column 9.

(1) identification of micro-organisms most effective in control, (2) determination of their environmental requirements, and (3) development of practicable methods for modifying environments to increase the micro-organisms' effectiveness.

Other investigations may contribute to our understanding of the disease or disclose relationships that make it more vulnerable to control. For example, why does western hemlock sometimes remain free from infection in active centers? Is it because of differences in root network patterns? genetic differences between local populations of hemlock? genetic differences between clones of the fungus? Why is the disease usually less damaging to old growth than to young growth? and why is it severely damaging in a few old-growth stands? Why are some trees killed physiologically (by parasitic attack on most of the living tissues of the root system) and others killed mechanically (by destruction of root and lower-trunk heartwood, with living tissues only moderately impaired)? To what extent do soil texture, moisture, and chemical composition directly affect survival of the fungus in dead material?

Such studies should be accompanied by others whose empirical results may be more immediately useful. For example, how is the disease affected by stand density? by various species mixtures, especially with hardwoods? Does early thinning disrupt the root network enough to retard spread of infection? Does inoculum survive as long in young-mature Douglas-fir roots, or in true fir roots, as in the massive roots of old-growth Douglas-fir?

Last but far from least, we need (1) accurate determinations of spread and damage rates, to provide a sound basis not only for the yield calculations essential for good management but also for economic analysis of cost-benefit ratios of control, and (2) techniques for differentiating, at acceptable cost, between disease hazard zones within stands, so that management procedures can be modified wherever such modification will be profitable.

Management Recommendations

Serious damage by laminated root rot in young stands on severely burned areas is conclusive evidence that slash-burning is not effective in control. A few infected root systems may be partly burned out, but most of the inoculum is too far underground to be affected by the fire. By decreasing the organic content and temporarily increasing the alkalinity of the soil, fire may even be somewhat adverse to natural controls.

Direct control methods now available are too expensive and offer little prospect of success. Trenching has proved unreliable for preventing spread of *Armillaria mellea* and *Fomes annosus*, and Wallis and Buckland (1955) found that new centers of *Poria weirii* infection continued to appear outside trenched centers. Although probably only the larger roots are long effective as reservoirs of infection, removal of these would usually require excavation to depths of 3 feet or more. Under field conditions, it is impossible to get penetration by chemical sterilizers into large, deeply buried roots whose interiors are often protected by layers of resin-impregnated wood.

Nevertheless, because of the tendency of laminated root rot to occur in

concentrations, judicious practice of "forestry by the acre" can reduce its economic impact:

1. Become familiar with the disease. Some infection is present in most Douglas-fir stands, and until better quantitative data are obtainable, forest managers must rely largely on personal judgment to determine where it is serious enough to require consideration in management.

2. Where infection is light, ignore it. The costs of excluding a few small centers from standwide operations are greater than the damage to be expected from them.

3. Do not waste money on precommercial thinnings where infection is abundant. Final yield will be considerably reduced by spread of the disease before commercial maturity is reached. Sometimes it may be possible to obtain a good crop by favoring species less susceptible than Douglas-fir, but even the less susceptible species are often infected when associated with highly susceptible ones.

4. When cutting in heavily infected stands, either clearcut or take only dead and dying trees. Infected trees are not windfirm, and partial cuts will be followed by heavy windthrow. Since dead trees give only slight protection to their neighbors, and trees with conspicuous crown symptoms are unlikely to live long, both can be removed without seriously impairing the stability of the stand.

5. Give logging priority to areas where the disease is most abundant — partly to salvage as much of the killed material as possible but principally because such areas are contributing little or no net growth. For example, lightly infected "forties" of the area shown in figure 4 were still making a net growth of 600 to 700 board feet per acre per year while heavily infected ones were losing volume.

6. Do not plant highly susceptible species where infection was abundant in the logged stand (as, for example, on the area shown in fig. 9). Although brush is usually well established on such areas and occupies them rapidly after logging, the certainty of damage to the new stand makes planting too risky an investment. Furthermore, when natural reforestation is delayed, as it often is, spread of infection to the new stand is reduced by death of the fungus in some of the old roots. Immediate planting, in contrast, increases the number of opportunities for growing roots to come in contact with infectious material.

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1970
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Mechanics of Debris Avalanching in Shallow Till Soils of Southeast Alaska

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INTRODUCTION

Excessive slope gradient and pore-water stress in glacial till soils of the Karta series are primary factors in debris avalanche and flow occurrence in recently logged areas of southeast Alaska. Initial field investigations have indicated that during months of low rainfall, lateral movement of seepage water in these soils is limited to a zone 2 to 6 inches thick, directly above an impermeable, unweathered till surface. Seepage occurs along interconnected soil voids and partings produced by downslope growth of rootlets above this surface (Bishop and Stevens 1964, Swanston 1967a).[1/]

During high rainfall periods, the soil becomes saturated, and the seepage zone thickens with substantial increases in flow. The increasing volume of water, moving laterally through the soil as saturated flow, causes a rise in the piezometric surface, with two important consequences: (1) increasing shear stress along potential sliding surfaces caused by rising seepage pressures and increasing unit weight of the soil materials, and (2) decreasing shear resistance resulting from increased pore-water pressure in the soil.

Historically, increased pore-water pressure has been shown to be a primary factor in the sliding mechanism of aggregate slopes. During periods of heavy rain, the quantity of water in the soil naturally increases. On saturation, excess water builds up, causing a rise in the piezometric level or "free" water level in the soil. The net effect is an increase in water pressure in the soil voids. Terzaghi (1950) has compared the effect of this increased pressure to the action of a hydraulic jack. The hydrostatic pressure of the water carries part or all of the weight of the overlying soil, in effect causing it to be jacked up or to "float," greatly reducing its "shearing resistance."[2/]

Soil stability analyses, based on theoretical soil mechanics and modified by engineering experience and practice, have become standard procedures for engineering works involving steep natural, and constructed slopes with a potential slide hazard. Detailed descriptions of theory and practical application are presented in a number of texts, among them Terzaghi (1950, 1963), Terzaghi and Peck (1960), Hough (1957), Wu (1966), Taylor (1965), and Eckel (1958).

Direct application of theoretical soil mechanics principles to the evaluation of the effects of various physical parameters operative on natural slope soils is difficult because of the large number of variables involved. A number

[1] Names and dates in parentheses refer to literature cited, p. 16

[2] Shearing resistance is the resistance to a stress causing or tending to cause two adjacent parts of a solid to slide past one another parallel to a plane or contact.

of assumptions based on idealized conditions at time of failure and certain mathematical simplifications are required which limit the reliability of quantitative results. Such an analysis, however, does provide a useful means of estimating the forces known or believed to be acting on the slopes where sliding has occurred and of characterizing slopes according to their slide susceptibility.

This paper (a) reports on the applicability of standard soil mechanics techniques to an evaluation of the factors affecting debris avalanching in the steep, shallow, permeable till soils of southeast Alaska and (b) quantifies the relationships between these factors which, up to now, have only been suggested on the basis of field observations.

STUDY AREA

Maybeso Creek valley on Prince of Wales Island was chosen as the principal area of research. It was the location of the first large-scale clearcut in southeast Alaska, and an extensive road system had been developed allowing easy access to recent debris avalanching. Weather records had also been maintained for 10 years before these studies, with major debris avalanches noted. Finally, the valley is the center of the type area for the Karta soil series (Gass et al. 1967).

Three slide areas (fig. 1) in the valley were chosen for detailed study on the basis of accessibility and similarity of occurrence. Each of these developed during a heavy rainfall period in October 1961 and occurred in the soil zone of a continuous till sheet covering an oversteepened (> 30°) south-facing slope. Timber was harvested during the summer seasons of 1955-58 by the high-lead method.

Figure 1.—The north slope of Maybeso Creek valley showing the location of the three slides analyzed.

METHODS

A stability analysis requires that the shear characteristics--effective cohesion, effective angle of internal friction, and unit weight--of the soils involved in sliding be obtained. It also requires that the effectiveness of pore-water stresses in the soil be evaluated and an approximate surface of failure determined.

Fundamental shear characteristics were obtained from undrained triaxial shear tests of five undisturbed soil samples[3] taken from the B horizon of the Karta soil at the head of the three recent debris avalanches studied. Estimates of bulk densities, moisture content, and particle size distribution were obtained from analyses of 19 additional randomly selected disturbed soil samples taken from the same areas.

Measurements of soil creep in the zone of sliding were made using strain gage probes modeled after those of Williams (1957).

The approximate surface of failure was determined in the field by assuming the base plane of the slide to be the surface of the unweathered till. The thickness of material above the slide plane and the gradient of the sliding surface were then measured. The toe of the initial zone of failure was taken as the first sharp break in slope within the slide scar and below the upper scarp. For convenience, the sliding surface was approximated by a "critical circle," tangent to the base plane and marked at its upper and lower limits by the upper slide scarp and the first break in slope not caused by bedrock. The critical circle had to satisfy the requirement that the ratio between the moment of forces tending to resist sliding (shear strength) and the moment of forces tending to cause sliding (shear stress) were at a minimum. This ratio is the factor of safety (F). At failure, F has a theoretical value of 1.

To determine the extent of pore-water pressure and evaluate its effect on mass movement in the till soils, piezometers were placed at selected sites within the three slide areas. These devices measure piezometric head or the height of rise of the free water above a reference surface. Pore-water pressure is directly related to piezometric head by the equation

$$\mu = h_p \gamma_w \qquad (1)$$

where μ is pore-water pressure, h_p is piezometric head, and γ_w is the unit weight of water.

The piezometer, based on an original design by Casagrande (1949), is a porous carborundum tube, 6 to 12 inches long and 1-1/2 inches in outside

[3] When structural effects are to be observed in engineering tests, soil specimens are cut from natural formations and hand trimmed to usable size, reducing sample disturbance to an absolute minimum. This is an "undisturbed sample."

Figure 2.—Piezometer being lowered into auger hole near slide 3.

diameter, connected to 1/2-inch outside diameter polyethylene tubing (fig. 2). Three-inch holes were drilled with a bucket auger to a point approximately one-half inch below the unweathered till surface intersecting the zone of water movement. If water flowed freely into the hole, it was prepared for piezometer placement. Before placement, the depth of the hole to the unweathered till surface and the length of the piezometer system were measured.

Ten piezometers were installed during the latter part of August in 1964 and 1965 for measurements during the autumn rainy season. The sites were on open slopes within and outside linear depressions near the zone of initial failure of the three study areas. The slope angle measured at each location was between 34° and 40° (∿ 70- to 85-percent grade). Piezometer locations are shown in figure 3.

RESULTS

SOIL CHARACTERISTICS

The Karta soil is a well-drained shallow podzol with a gravelly, silt-loam texture (Gass et al. 1967). Mechanical analyses of 19 disturbed samples reveal it to be well graded, with a corresponding particle size distribution high in silt and sand with less than 10 percent being clay size particles.

Examination of the size fractions under a binocular microscope indicates the majority of particles to be angular to subangular in shape, composed of fragments of graywacke and argillite mixed with individual grains of quartz, feldspar, and ferromagnesian minerals.

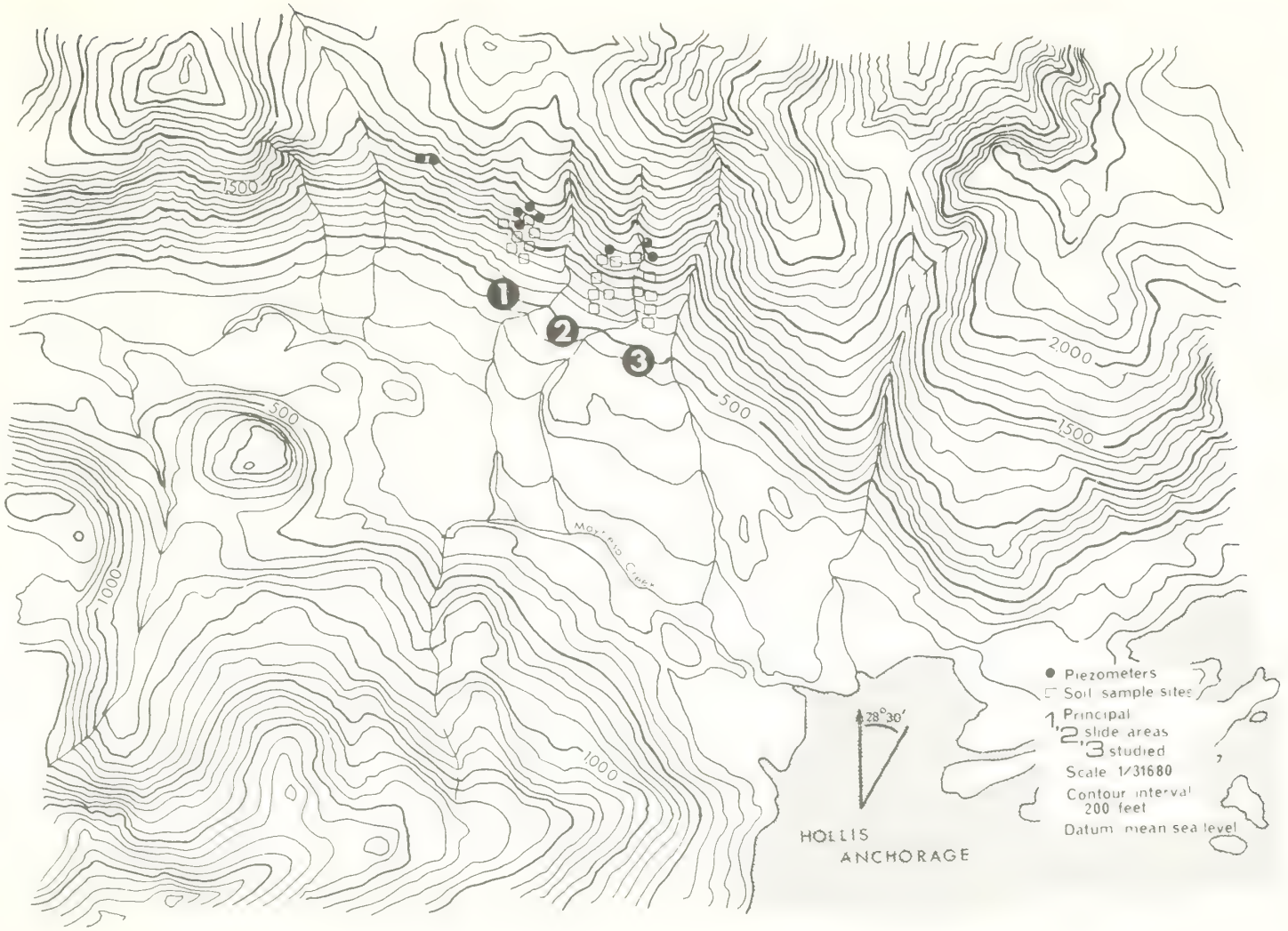

Figure 3.—Topographic map of a portion of Maybeso Creek valley showing locations of landslide study areas and sample and instrument sites.

Tests for Atterberg limits[4] made on five representative samples were inconclusive. In general, values were too low for interpretative purposes and are not reported here. Lack of well-defined Atterberg limits for the samples tested suggests that the effective internal cohesive forces in the slide-prone soil are minimal.

Triaxial shear tests on the five undisturbed samples[5] indicate an effective cohesion ($\bar{C}$) of 0 and an angle of internal friction of 37°. An effective cohesion of 0 supports the findings of the Atterberg tests.

Soil creep measurements[6] indicated moderate and recordable amounts of movement in the organic A horizon and upper part of the weathered B horizon with rate of creep estimated as one-fourth inch per year at the surface. The surficial soil apparently moves as a flow mass with no well defined shear zones. No significant deep-seated soil creep was indicated, ruling out a consideration of progressive failure of the slope at this time.

Surface loading of the soil due to weight of trees in the zone of initial sliding was considered negligible. Field observations and excavation of stumps in the study areas indicated that most of the weight of individual stumps was carried by lateral roots that penetrated the soil profile and lay on the compact, unweathered till surface (Bishop and Stevens 1964, Patric and Swanston 1968). These "lateral" roots were, in turn, anchored by small-diameter sinker roots that penetrated the upper 6 to 12 inches of the compact till surface. The decay of these roots following clearcutting or mortality may be an important factor in reducing resistance to sliding and will be taken into account in the analysis. It appears that any cohesion exhibited by these soils must result primarily from such factors as organic colloids, capillary tension, or anchoring effect of roots.

An effective 37° angle of internal friction serves as a good indication of the natural instability of these slopes. This angle is well above the theoretical maximum angle of stability (angle of repose)[7] for soil of the Karta type. The angle of repose can thus be used as a reference angle marking the maximum slope at which a soil of the Karta type will stand when unaffected by forces other than gravity and friction.

Unit weight values of the 19 random disturbed samples at field capacity (approximately 65-percent moisture content) averaged 111 pounds per cubic foot. Unit weights (air dry) were somewhat lower, averaging 103 pounds per cubic foot at a moisture content of 37 percent. These averaged values lie

[4] Atterberg limits describe the states of consistency or firmness of a fine-grained soil.

[5] Triaxial shear tests performed by Michigan State University, Civil Engineering Laboratory.

[6] D. J. Barr and D. N. Swanston. Measurement of creep in a shallow, slide-prone till soil. (In preparation for publication.)

[7] The angle of repose is the angle between the horizontal and the slope of a heap of sand produced by pouring dust-dry sand from a small height. Experimentation and engineering field experience indicate that the angles of internal friction for loose sands, silts, and silty sands are similar, varying around an angle of repose of 34° (Terzaghi and Peck 1960, p. 66).

within the range of expected unit weight values for the Karta soil[8] and will be used in this paper as an index of the unit weight of the slide-prone soils.

PORE-WATER PRESSURE MEASUREMENTS

Pore-water pressure measurements during the fall rainy season (September through November) were begun in 1964 and continued in 1965 (Swanston 1967a, b). Direct correlation of both the 1964 and 1965 field data with rainfall variations recorded in the valley indicate a close relationship between these parameters.

A more detailed regression analysis of the 1965 field data (Swanston 1967b) revealed a curvilinear relationship between rainfall, pore-water pressure, and slope position, allowing us to make direct approximations of prevailing piezometric levels at the time and point of initiation of known landslide activity (fig. 4). Within the three selected study areas, rainfall conditions and slope position at the time of initial slope failure indicate conditions of total soil saturation to be in effect. Thus, for purposes of slope analysis, we can assume that the slide-prone soils were subjected to maximum pore-water pressures at the time of initial slope failure.

[8] Freeman Stephens, Soil Scientist, U. S. Forest Service Region 10, personal communication.

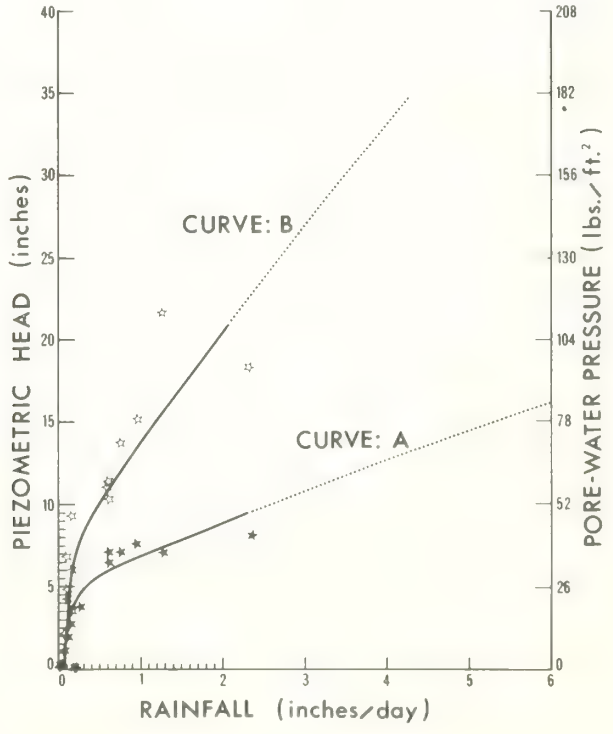

Figure 4.—Curvilinear relationship of average piezometric head vs. rainfall for two slide-prone slope locations. Curve A represents piezometric head on the open slopes; Curve B represents piezometric head within linear drainage depressions (after Swanston 1967b).

STABILITY ANALYSES

Final stability analyses were based on theoretical soil mechanics in homogeneous materials, with results modified by engineering experience. The analyses were made using "the method of slices," as described by Wu (1966) and Hough (1957). This method allowed shear strength-stress relationships and the factor of safety to be calculated with reasonable accuracy. It is especially useful when pore pressure effects are being considered. With this method, the soil mass as defined by field measurements is diagramed and divided into a number of segments (fig. 5). The forces acting on each segment are then evaluated assuming equilibrium conditions. Equilibrium occurs with balance between opposing forces.

If the shear stress is not sufficient to produce failure, then the ratio of shear strength to shear stress represents the factor of safety mentioned earlier. The factor of safety is given by the equation:

$$F = \frac{\Sigma[\bar{C}\Delta L + (\Delta W_n + Q_n - \mu\Delta L) \cos \alpha \tan \bar{\phi}]}{\Sigma(\Delta W_n + Q_n) \sin \alpha} \qquad (2)$$

where ΔW_n represents the weight of the soil, Q_n represents surface loading, μ is pore-water pressure, ΔL is slope width of each section, α is slope angle, $\bar{\phi}$ is effective angle of internal friction and $\bar{C}$ is effective cohesion of the soil.

Since surface loading of the slide-prone soils is assumed negligible, the term Q_n can be removed from equation 3 and the factor of safety becomes:

$$F = \frac{\Sigma[\bar{C}\Delta L + (\Delta W_n - \mu\Delta L) \cos \alpha \tan \bar{\phi}]}{\Sigma\Delta W_n \sin \alpha} . \qquad (3)$$

The greatest pore pressure at failure in each of the three slide zones analyzed was taken as the pore-water pressure developed when the soil profile became completely saturated. Dimensions needed for solving equation 3 were scaled from longitudinal sections of the initial failure zone (fig. 5). The weight of each segment was determined by multiplying the segment area (from the scaled diagram) by the soil unit weight. The slope angle (α) was also measured directly from the diagram.

Calculation of F for the individual slide areas, using the previously determined shear characteristics of $\bar{\phi} = 37°$ and $\bar{C} = 0$, resulted in values for the F factor which are less than 1 (0.395, 0.396, and 0.449 for slides 1, 2, and 3).

At failure, F is assumed to be 1. The discrepancy existing here was removed by assuming the existence of a cohesive force in the soil that did not show up directly in laboratory tests. The existence of such a force (expressed as $\bar{C}_a$) is well illustrated in the field by many extremely steep but stable natural slopes.

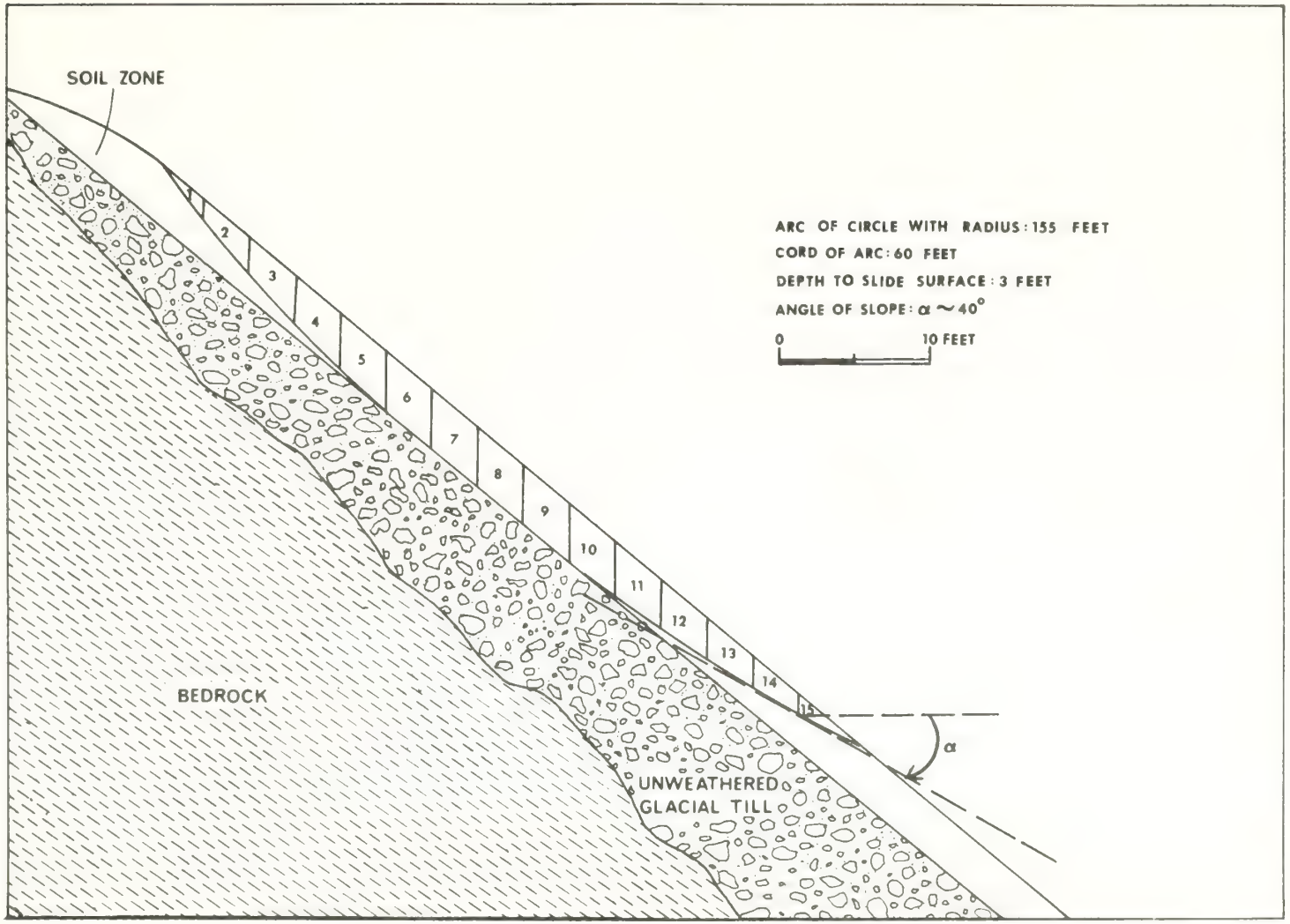

Figure 5.—Circular arc constructed from the measured dimensions of the initial zone of failure in each of the three slides studied.

This force may result from the interaction of several different factors. Capillary tension causes a limited amount of "apparent cohesion," prior to complete saturation of the soil profile. Some cohesion probably also results from the high organic colloid content (reported by Stephens 1967) of the slide-prone soils. A potentially large stabilizing force is produced by root penetration through the soil and into the compact till. Regardless of its primary cause, such a force may be estimated by setting the value of F at 1 and calculating an approximate value of $\bar{C}_a$ for each slide mass at failure and under the influence of pore-water pressure. Thus

$$F = 1 = \frac{\Sigma[\bar{C}_a \, \Delta L + (\Delta W_n - \mu \Delta L) \cos \alpha \tan \bar{\phi}]}{\Sigma(\Delta W_n) \sin \alpha}$$

and

$$\bar{C}_a = \frac{[1] \, [\Sigma \Delta W_n \sin \alpha] - [\Sigma(\Delta W_n - \mu \Delta L) \cos \alpha \tan \bar{\phi}]}{\Sigma \Delta L} . \qquad (4)$$

Calculations of "apparent cohesion" from equation 4 yield values for $\bar{C}_a$ of 89.15 pounds per square foot for slide 1, 83.9 pounds per square foot for slide 2, and 69.0 pounds per square foot for slide 3.

Using these $\bar{C}_a$ values, an F value at maximum soil strength for each of the study sites was also obtained. The F values of the slope with soils at their field capacity and air-dry states in the absence of active pore-water pressure were calculated and compared to determine the natural stability of the slopes and the effectiveness of pore-water pressure as a stability reducer. The calculated factors of safety for the soil at field capacity are 1.49, 1.57, and 1.61 for slides 1, 2, and 3. Those of soil in the air-dry state are 1.55, 1.62, and 1.66. The difference in F value for a soil at wet and dry unit weights is small. These values indicate more than adequate stability under natural soil and slope conditions and in the absence of water pressures, since values as low as 1.1 are frequently considered adequate for highway and railroad slopes (Hough 1957). *At complete saturation, and thus maximum pore-water pressure, these values are reduced to a factor of safety approaching 1 and sliding becomes imminent.*

A simple check can be made on the results of the method of slices by analyzing the forces acting on a block of unit thickness having the soil and slope characteristics on a slope of infinite length (fig. 6). The results are certainly less exact but provide an index of the correct magnitude of forces involved.

In Maybeso valley:

$\gamma_{sat.} = 111$ lbs./ft.^{3}

$\gamma_w = 62.4$ lbs./ft.^{3}

$\bar{\phi} = 37°$

$h = 3$ ft.

$\alpha = 37°$

$\Delta W = \gamma_{sat.}\, h$

$\tau = \Delta W \sin \alpha = \gamma_{sat.}\, h \sin \alpha$

$\sigma = \Delta W \cos \alpha - \gamma_{sat.}\, h \cos \alpha$

$\bar{\sigma} = (\gamma_{sat.}\, h - \gamma_w h) \cos \alpha$

$S = \bar{C} + \bar{\sigma} \tan \bar{\phi}$

Factor of safety $(F) = \dfrac{\bar{C} + \bar{\sigma} \tan \bar{\phi}}{\tau}$ (at failure F = 1)

thus,

$$1 = \frac{\bar{C} + (\gamma_{sat.}\, h - \gamma_w h) \cos \alpha \tan \bar{\phi}}{\gamma_{sat.}\, h \sin \alpha}$$

$$\bar{C} = \gamma_{sat.}\, h \sin \alpha - (\gamma_{sat.}\, h - \gamma_w h) \cos \alpha \tan \bar{\phi}$$

$$= (111)\ (3)\ (0.602) - [(111)(3) - (62.4)(3)][0.799][0.754]$$

$$= (200.46) - (333.00 - 187.2)\ (0.799)\ (0.544) - (145.8)\ (0.602)$$

$\bar{C}_a = 112.631$ lbs./ft.^{2}

using this value of $\bar{C}_a$, in the absence of pore-water pressures

$$F = \frac{112.00 + 200.46}{200.00} = 1.56.$$

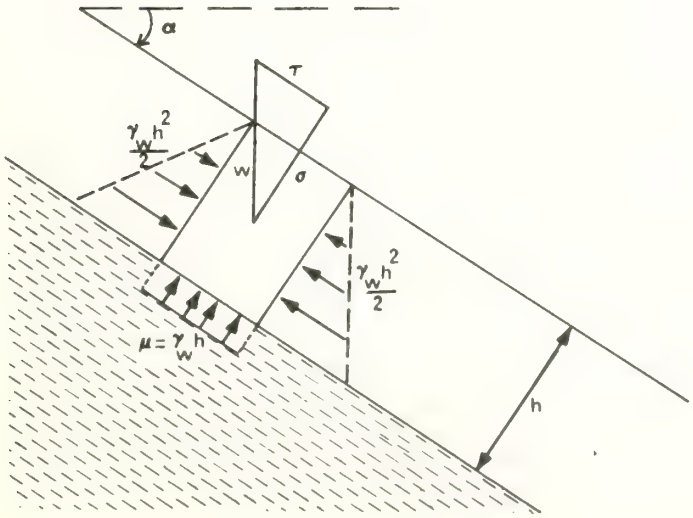

Figure 6.—Forces acting on a soil block having the soil and slope characteristics of unit thickness on a slope of infinite length. These forces consist of the weight of the soil ($W = h\gamma_{sat.}$), the normal and shear stresses (σ) and (τ), pore-water pressure (μ), and the lateral pressures on the block $\frac{\gamma_w h^2}{2}$ which cancel each other. α is the angle of slope, γ_w, unit weight of water, and $\gamma_{sat.}$, unit weight of soil.

DISCUSSION

This study verifies a number of previous assumptions concerning the effects of slope angle and various soil conditions on stability of steep slope till soils in southeast Alaska. In addition, many of these relationships have been quantified into values usable by the land manager for determining stability potential for specific management areas with this soil type.

High pore-water pressure stands out as the most effective triggering force for debris avalanches with maximum effect at complete saturation of the soil profile in the area of initial sliding. Field measurements in Maybeso valley indicate that such a completely saturated condition requires a rainfall intensity in excess of 6 inches in 24 hours, a condition known to have occurred during the 1961 period of slide activity in the valley and elsewhere in southeast Alaska (Bishop and Stevens 1964, Swanston 1967a). Similar intensities have been reported in the valley relating to sliding activity in 1959.

Swanston (1969) has shown that debris avalanching in southeast Alaska, regardless of soil type, is concentrated in areas of recurring high precipitation. They occur especially frequently in areas characterized by the same storm precipitation rate indicated in Maybeso valley. Thus, till soil areas with rainfall intensities frequently at or above the rate of 6 inches in 24 hours or which lie within areas of recurring high precipitation can be expected to have a high debris avalanche potential.

It is also clear that an apparent cohesion for the slide-prone soils does exist and is due to external factors not reflected directly in the physical properties of the soil. In the areas studied, this value varies from 69 to 89 pounds per square foot. Such an apparent cohesion is most likely to have resulted from the anchoring effect of roots growing through the slide-prone weathered till and into the underlying compacted and unweathered till. Bishop and Stevens (1964) suggested this possibility. They also noted an apparent 3-year lag in slide acceleration after logging and suggested that this may be the time necessary for root deterioration to reduce soil shear strength to a low enough value for sliding to occur. More recent investigations of root deterioration following logging in southeast Alaska[9] indicate a definite 3- to 5-year lag in root strength reduction and appearance of decay.

The upper limit of stability lies at or near 34° (the angle of repose of the soil). With decreasing slope, shear strength and the factor of safety increases. This can be seen by once again considering equation 5 for the factor of safety. If we assume a unit volume of soil not influenced by pore-water pressure and remove summation signs, equation 4 reduces to

$$F = \frac{\bar{C}\Delta L + W_n \cos \alpha \tan \phi}{W_n \sin \alpha} . \qquad (6)$$

[9] D. N. Swanston, and W. J. Walkotten. The effectiveness of rooting as a factor of shear strength in the Karta soil. Study No. FS-PNW-1604:26; report on file at the Pacific Northwest Forest and Range Exp. Sta., Northern Forest., Juneau.

Under the assumed conditions, $\bar{C}$ is a constant and ΔL or thickness of the soil mass is unity. W_n is also unity, and ϕ is constant. With decreasing slope, sin α decreases faster than cos α. The F value correspondingly increases as the slope gets smaller. *This points up the strong relationship between slope angle and slide susceptibility.*

Strahler (1956) has developed a method of slope analysis that expresses this relationship particularly well. By determining the sines of the slope angles for a large number of points in an area, an isosinal map can be made by contouring the values. For cohesionless soils, the sine of the slope angle represents that part of the total gravitational force acting to produce downhill sliding or flowage of rock particles or fluids on the surface. A soil particle located at point "P" on the slope is affected by forces $F_g = mg.$, where m is mass in pounds and g is the acceleration of gravity in feet per second per second, F_s is shear stress (τ) in pounds per square foot. F_s and F_n are components of F_g. The elementary trigonometric relationship of the principal forces acting on a soil particle on a slope (Strahler 1956) is depicted in figure 7.

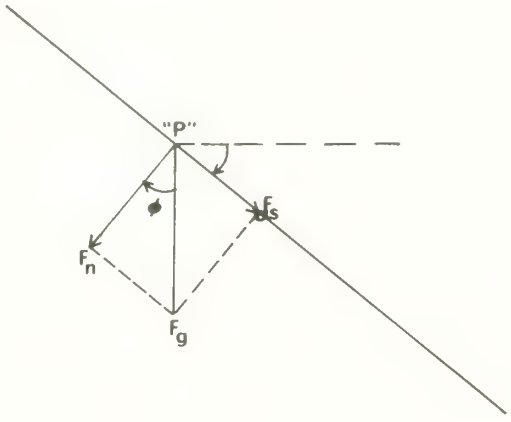

Figure 7.—Principal forces acting on a soil particle on a slope (after Strahler 1956). F_g represents the force of gravity acting on the particle, F_s is the shear stress, and F_n is the force normal to the surface. α is the angle of slope and ϕ is the angle of internal friction.

$$\sin \phi = \frac{F_s}{F_g} \frac{\tau}{F_g}, \text{ by geometry, } \alpha = \phi.$$

When a unit mass of soil surrounding point "P" on the slope is considered, the downslope force [shear stress (τ)] operating on that mass is given as $\tau = F_g \sin \alpha$, the equation for the shear stress in a cohesionless soil. Note that F_g in this case represents the column or weight of material.

Thus, the isosinal contour map tells the general location and distribution of shearing stresses produced by gravity on a cohesionless soil slope. Simply stated, for a cohesionless soil the factor of safety as defined by Terzaghi and Peck (1960) is:

$$F = \frac{\tan \phi}{\tan \alpha}. \qquad (7)$$

As the slope angle approaches the internal friction angle, F approaches 1 and failure is imminent. The isosinal contour corresponding to the sine of the internal friction angle can then be used as the critical isosine around which sliding is most likely to occur.

A nonrigorous isosinal slope analysis, or more simply *slope angle analysis*, can supply useful results as to the effect of slope angle on soil stability and the most likely areas of future slide occurrence.

CONCLUSION

Studies in the Maybeso valley show that the majority of debris avalanches and flows develop on slopes greater than 34° and are especially frequent around a critical angle of 37°. On an isosinal contour map of Maybeso valley (fig. 8), this angle is represented by the critical contour 0.6, the sine of 37°. Above this critical contour, sliding is imminent with the destruction or disruption of any cohesive forces acting to hold the soil in place. Below the critical contour is a zone of decreasing instability. The zone of instability thus defined is located principally in the deeper stream notches and in a narrow band near the 1,200-foot contour. The narrow band in the vicinity of maximum slide activity corresponds to the steep face of a till shoulder marking the upper limit of younger till.

By construction of an isosine map, or more simply mapping of slope angles, areas of general slope instability within a watershed can be located and the feasibility of applying preventive or control measures determined. If the area of instability is a bedrock cliff, no additional consideration need be given. If the area lies within some of the best timber stands, serious thought should be given to harvesting techniques and road construction in the critical area.

Figure 8.—Isosinal contour map of the Maybeso Experimental Forest, Prince of Wales Island, Alaska. The sine of the angle of slope, or "isosine," expresses slope in terms of that part of the total gravitational force which tends to produce downhill sliding or flow of rock particles or fluids on the surface. The same lines can also be used to express slope angle or percent grade directly. Initial slope angles were obtained from a topographic map at a scale of 1:31,680 by counting the number of contour lines intersected by a perpendicular line, bisecting a slope point and corresponding to a ground distance of 200 feet (≈ one-half inch at map scale). The heavy black contour denotes the critical isosine or slope angle above which sliding is imminent under the best of conditions.

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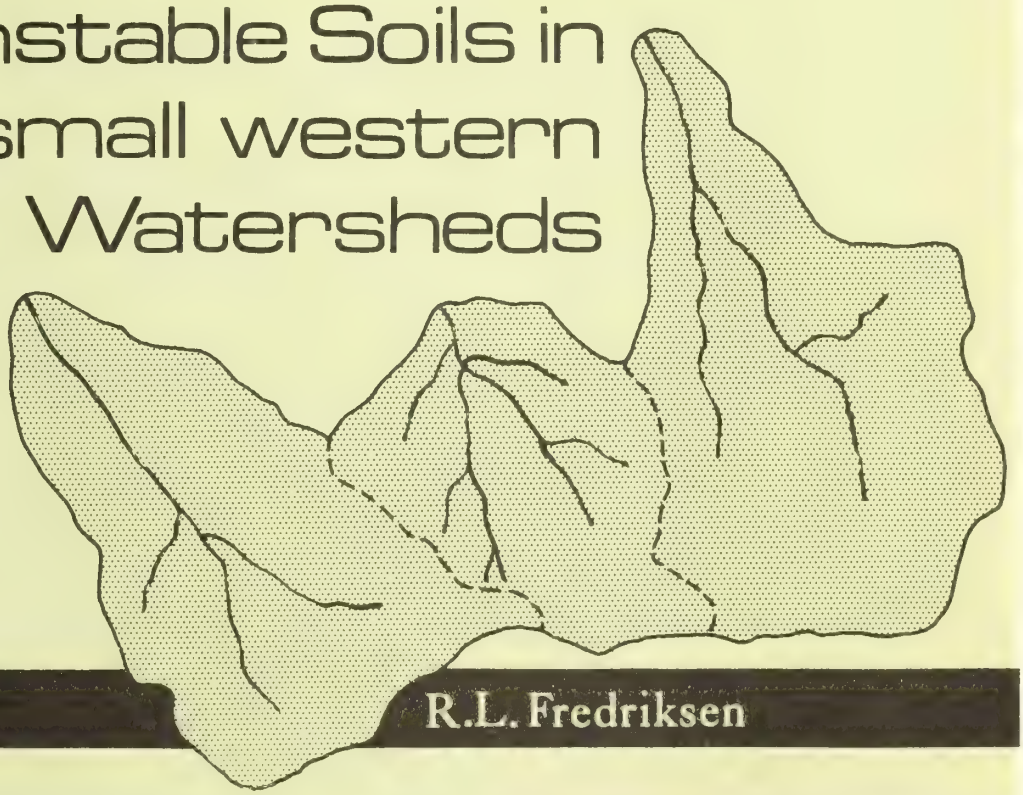
Erosion and Sedimentation Following Road Construction and Timber Harvest on Unstable Soils in three small western Oregon Watersheds



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INTRODUCTION

Douglas-fir stands in the mountainous topography of western Oregon are usually harvested in patch clearcuts by high-lead yarding to forest roads. Main-line logging roads are normally located in valley bottoms and along ridgetops. Where side slopes are too long to reach timber, one or more levels of midslope road may be necessary. In the Western Cascades Range Province (Peck et al. 1964), in which this study was conducted, about 430 miles of logging road are constructed each year to harvest 1.4 billion board feet of timber from National Forest land.[1/] Harvest of timber from these lands under U. S. Forest Service management supplies 27 percent of the annual income to counties within this province.[2/] Although the local economy is largely dependent on income from timber, soil stability problems related to timber harvest (Rothacher and Glazebrook 1968) should be another consideration in management of the forest.

The U. S. Forest Service began a watershed study in 1952 to evaluate the impacts of timber harvest on water quality. The characteristics of three small watersheds while undisturbed have been described in detail by Rothacher et al. (1967). This article will report on erosion in these watersheds and sedimentation rate in their contributing streams after road construction, timber harvest, and debris burning.

THE STUDY

The study was conducted on three small experimental watersheds located on the H. J. Andrews Experimental Forest about 50 miles east of Eugene, Oregon (fig. 1). Timber on one watershed was harvested by a method used throughout the province for at least 20 years. In this method of harvest, small clearcuts are separated by uncut blocks of forest. Logs on the small clearcuts are moved to landings (yarded) by high-lead cable methods where they are loaded onto trucks and transported from the watershed on a system of parallel logging roads. This type of harvest is designated "patch-cutting" in this report. Skyline yarding *without forest roads* was chosen as the second harvest method because (1) forest roads were already highly suspect as a major source of increased sedimentation following timber harvest, and (2) Wooldridge (1960) had shown that surface soil disturbance is minimized by skyline yarding. The watershed which was skyline yarded is referred to as "clearcut" in this report. The third watershed remained undisturbed and has served as a "control" throughout the experiment.

The following details the harvesting done on the watersheds.

Patch-cut Watershed

One watershed (250 acres) was harvested by the conventional practice of patch-cutting with a system of logging roads (fig. 1). Three levels of roads completed in 1959 covered a total distance of 1.65 miles and 6 percent of the drainage--4 percent initially bare soil on fills and cutslopes and 2 percent stabilized road surface (fig. 1). Construction met Forest Service specifications for an all-weather road with culvert cross drains, base rock, and a crushed

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[1/] Unpublished information from Region 6, U. S. Forest Service.

[2/] Unpublished information from Oregon State Tax Commission, Salem, Oreg.

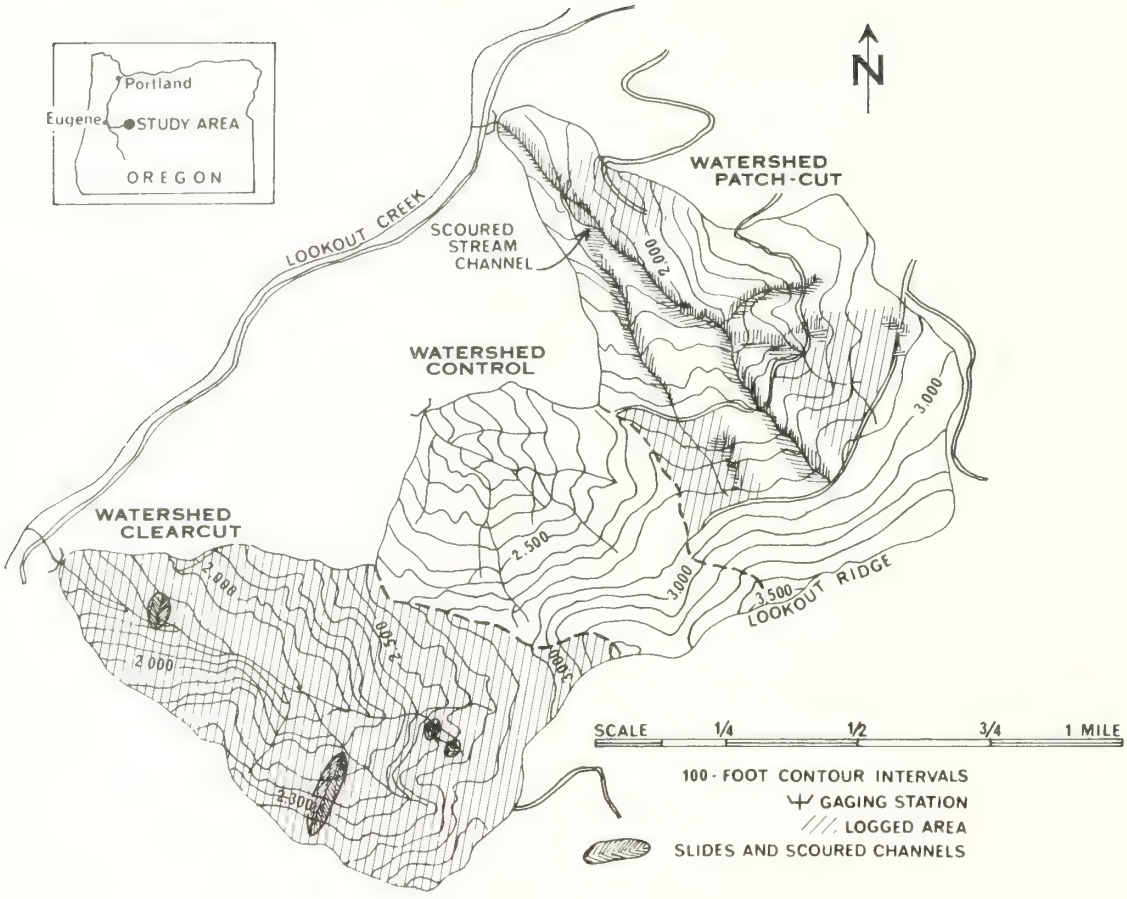

Figure 1.—Experimental watersheds, H. J. Andrews Experimental Forest.

rock running surface. Stream crossings were soil or rock fills depending on available material. Although part of the excavated material was used to construct fills, some was wasted on the hillside below the road. Construction exposed 2.5 acres of soil on backslopes, 8.0 acres on fillslopes, and 5.1 acres on the roadbed. Backslopes and fillslopes were seeded with a grass-legume mixture in the fall of 1959. Although the seeding did not produce a permanent vegetative cover, the straw mulch applied with the seed temporarily protected the soil from rain.

Logging of old-growth Douglas-fir timber by high-lead cable methods was completed during the winter of 1962-63 on three clearcuts of 13, 20, and 28 acres. The logging removed timber from 25 percent of the watershed (fig. 2). Logging debris was burned in September 1963.

Figure 2.—Patch-cut watershed contains three small clearcuts totaling 25 percent of the watershed area and 1.65 miles of logging road.

Clearcut

On the second watershed, timber harvest was begun in the fall of 1962 and completed during the summer of 1966 (figs. 1 and 3). Skyline yarding equipment removed timber from the entire 237 acres of this watershed. With this method, the back end of the logs are dragged to a fixed overhead cable, then lifted free of the ground for transport downhill to the landing. No roads were constructed in this watershed. Debris burning in October 1966 consumed most of the fine logging debris on the slopes and that accumulated in the stream channel. Cull logs remaining in the channel were cut and piled above high water one-fourth mile upstream from the gaging station to prevent the formation of debris jams.

Figure 3.—Clearcut watershed contains no roads. Timber was yarded by a skyline cable system.

CHARACTERISTICS OF THE WATERSHEDS

The watersheds are in the province of the Western Cascades Range of Oregon, a land mass that slopes generally westward from the Cascade Crest and extends from

the Columbia River on the north to the Siskiyou Mountains on the south. Parent materials for soils in the watersheds are predominantly tuffs and breccias, volcanic ash deposits of Miocene to Oligocene age.

Topography

The watersheds occupy strongly dissected topography characteristic of western Cascades relief (fig. 1). They occupy the sideslope of Lookout Ridge facing to the northwest and rising 1,400 to 1,850 feet in a mile from valley floor to back ridge (table 1). The three small streams draining these watersheds occupy channels that are deeply incised into the hillside. Sideslopes and headwalls of the small drainages exceed the sideslope of the main ridge by 20 to 30 percent. Slopes range up to 110 percent with a substantially larger area of steep slopes in the clearcut and control watersheds compared with the patch-cut watershed.

Hydrology

A mean annual precipitation of 90 inches consists primarily of rain during the winter months from October through April. Peak runoff in the streams follows long-duration, low intensity rainstorms, often associated with melting snow, that may deliver up to 13 inches of rain in 4 days. Warm rainfall on a snowpack causes the steepest stream rises, and we assume that the largest volume of water is held in temporary storage in the soils of the watersheds under these conditions. Most of the erosion and sedimentation to be reported here occurred during three runoff events of this latter type.

Soils

Soils developed from tuff and breccia parent materials are more common in the watersheds than those from basalt and andesite (Rothacher et al. 1967). They commonly have a thin granular and porous A1 horizon covered by 1 to 3 inches of litter. It has been noted that these soils resist surface erosion as long as this horizon is intact and uncompacted. Medium to fine textured B horizons are often underlain by weathered tuff and breccia parent materials to considerable depths--sometimes greater than 50 feet. These soils are generally very porous and, therefore, rapidly conduct water through the profile (Dyrness 1969).

Soils store maximum amounts of water during the winter months. Water affects the mass stability of the soil mantle in two ways. First, it increases the bulk weight of the soil and, therefore, the downhill gravity force acting on the soil mantle. Second, it reduces the resistance of the soil mantle to shear failure by reducing the cohesive forces that hold soil particles together. Other factors adding to the mass instability of these soils are their large water storage capacity (Dyrness 1969) and the presence of expanding clays in the subsoils of some of the soil series.[3/] Because of these soil properties, abundant rain, and steep sideslopes, the dominant erosion process is by landslides.

DISTURBANCE CAUSED BY LOGGING AND BURNING

A dense cover of vegetation and a nearly complete mat of forest floor material (table 2) protects the surface soils from erosion while the forest remains undisturbed. Harvest operations and broadcast burning on two watersheds destroyed a large part of the existing shrub and ground cover. Burning, which followed completion of logging

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[3/] Robert C. Paeth. Genetic and stability relationships of four western Cascade soils. Ph. D. thesis, Oreg. State Univ., 126 pp., 1970.

Table 1.--*Topography of the three watersheds*

Item	Patch-cut	Clearcut	Control
Area . . . . . acres . .	250	237	149
Length . . . . . feet . .	5,280	4,950	3,630
Elevation change . . . . . feet . .	1,850	1,400	1,500
Mean slope . . . . . percent . .	53	63	61
Area greater than 80 percent slope . . . . . percent . .	3	14	14

Table 2.--*Total understory vegetation cover and exposed mineral soil after clearcutting of timber and after burning of logging residue*

Year	Patch-cut watershed			Clearcut watershed		
	Condition	Vegetation cover[1/]	Bare ground[2/]	Condition	Vegetation cover[1/]	Bare ground[2/]
		Percent			*Percent*	
1962	Undisturbed	70	3	Undisturbed	86	4
1963	Clearcut	10	16	Being harvested	--	--
1964	After burning	15	29	Being harvested	--	--
1965	Revegetating	49	28	Being harvested	--	--
1966	Revegetating	54	30	After logging	54	12
1967	Revegetating	62	28	After burning	30	53
1968	Revegetating	80	27	Revegetating	76	54

Source: Dyrness--1965, 1967b, and unpublished data.

[1/] Sum of leaf cover in the understory tree layer, shrub layer, and herb layer is additive.

[2/] According to this classification, bare ground may occur under leaf cover, and vegetation cover plus bare ground can add to greater than 100 percent.

by several months, reduced vegetation cover more on the patch-cut than on the clearcut watershed. In the clearcut watershed, regrowth of some more fire resistant species during the 3 years required to complete logging may have been responsible for the large cover of vegetation the year following burning (1967). Revegetation was rapid in the case of both watersheds, but a sizable proportion of the soil surface remained bare of litter for several years following burning. On the patch-cut watershed, the herb-rich vegetation established the first 2 years following burning gradually gave way to a rapidly expanding cover of shrubs and trees. By 1968, the total vegetation cover on the clearcuts in the patch-cut watershed exceeded the cover measured under the undisturbed forest in 1962.

Dyrness (1967b) measured the effect of the logging operations and broadcast burning on disturbance to the soil and litter layer. High-lead logging in the patch-cut watershed resulted in double the area of deep soil disturbance (10 percent) and nearly three times the area of compacted soil (9 percent) of that in the clearcut watershed. A larger proportion of the clearcut watershed was burned, and a slightly larger fraction of the burned area was severely burned. The severity of the burn on these watersheds was moderate. Dyrness and Youngberg (1957) and Tarrant (1956), studying intensity of slash burning, found the severely burned area to range from 2.8 to 8.0 percent of the total area burned.

Class	Patch-cut	Clearcut[3/]
	Percent	
Severely burned	6.2	6.8
Lightly burned	50.2	61.5
Unburned	42.8	28.1
Nonsoil areas	.8	3.6
	100.0	100.0

[3/] Unpublished data, C. T. Dyrness.

EROSION BY LANDSLIDES

Two periods of landslide erosion increased the sedimentation rate in the patch-cut watershed. The first landslide, in December 1961, originated from soil spilled over the hillside below a road being constructed (Fredriksen 1963). This landslide, as is often the case, triggered a mudflow which scoured over one-half mile of the stream channel, depositing about 5,000 cubic yards of debris where the stream passes through the lower logging unit (fig. 1).

Thirty-two landslides occurred in the patch-cut watershed during the storm of December 1964. They moved an estimated 39,200 cubic yards of soil within the watershed.

Condition of terrain	Number	Volume
		Cubic yards
Roads and clearcut	2	230
Roads and green timber	4	36,070
Clearcut only	11	1,200
Green timber only	15	1,700
Total	32	39,200

All but three landslides were adjacent to stream channels. Although the size of most of these landslides ranged from 5 to 1,000 cubic yards, the largest volume came from a single slide located at the head of the principal drainage just downstream from the upper road (fig. 1). Few slides occurred adjacent to roads, but these few accounted for 93 percent of the total volume. The lesser importance of landslides at clearcut and green timber sites is indicated by a much smaller volume of soil lost. Material from nine of these slides (two in clearcut and seven in green timber for a total of 1,540 cubic yards) was not removed from the channel. These landslides occurred after the last mudflow passed down the stream channel, and some of them may have occurred a

month later during the storm of January 28, 1965. Subsoils exposed adjacent to streams left 2.5 acres of bare soil along channel margins. The landslides of 1961 and 1964-65 created three new types of sediment sources: (1) exposed soils along streambanks, (2) regraded stream channels, and (3) exposed soil on landslide areas. Erosion from these sources has continued to the present time.

Landslide erosion in the clearcut watershed occurred during the January 1965 storm. An estimated 800 cubic yards of soil moved in four landslides (fig. 1). The soil from these landslides came to rest behind logging debris which had accumulated in the stream channel. Although a large amount of this soil was carried away by the stream after the logging debris was burned in 1966, considerable soil remains in the stream channel as terraces.

Erosion in the control watershed has been confined to the stream channels and streambanks. No landslide erosion has occurred here, but landslides have been observed in other undisturbed areas in the Experimental Forest.

METHODS

Field Sediment Measurements

Streamflow was measured at trapezoidal flumes where the streams leave the watersheds. Duplicate depth-integrated water samples for suspended sediment analysis were taken here in pint bottles. Most of the 350 suspended sediment samples for each watershed were taken during periods of storm runoff. Coarse (bedload) sediments were measured annually in small, 0.04-acre, debris basins, which trapped bedload but passed fine sand and silt-size particles.

Determination of Sediment Yield

Mean suspended sediment concentration was obtained in the following manner for the 6-month winter period from November through April. This period includes the important peak flows of these streams and 89 percent of the annual runoff. Streamflow was divided into discharge classes from low to peak flows. Hours of streamflow in each class were further subdivided according to the time that the stream was rising and falling. Mean suspended sediment concentration for each class was estimated separately for rising and falling flows from hand-fitted curves relating concentration to streamflow. As sedimentation rate changed with condition of the watershed, new curves were drawn. Six distinctly different sedimentation rates were evident in the data from the patch-cut watershed, five rates for the clear-cut watershed, and a single rate for the undisturbed watershed.

Annual bedload yield was derived from the volume of sediment trapped in the basin and an estimated sediment density of 62 pounds per cubic foot. Total sediment yield was the sum of the estimated suspended and bedload yields for each watershed and year.

Accuracy and Precision

The mean concentration data in figure 4 are subject to several sources of error. Errors are of the following types: (1) variation in sediment concentration about the hand-fitted curves, (2) poorly defined data near peak flows, (3) error in concentration due to sampling technique, and (4) errors in partitioning sediment into a suspended and a nonsuspended fraction. Curve-fitting errors (type 1) are small and compensating. Type 2 errors may be large. Only the 1964-65 sedimentation peak for the patch-cut watershed, shown

by the broken line in figure 4 is of this type. The type 3 error is systematic in that openmouthed bottles underestimate the true concentration carried by the stream. The type 4 error is small since particles larger than fine sand were removed from the sample. The suspended sediment data underestimates the true concentration carried by the stream, particularly when the concentrations were large. When the curve is well defined, estimates are ± 10 percent or better.

Bedload sediment measurement errors are probably no larger than ± 5 percent of the values indicated in figure 5, except for the years 1965 and 1966 at the patch-cut watershed. In 1965, an unknown but comparatively small quantity of the material carried in mudflows was lost downstream. In 1966, part of the bedload trapped in the new basin was lost when the dam failed.

RESULTS

Sedimentation From Undisturbed Watersheds

All three streams carried only small amounts of sediment while their watersheds were undisturbed. Mean annual winter season concentration ranged from 1 to 45 parts per million (p.p.m.) of suspended sediment in response to the proportion of winter flow that occurred as storm runoff (fig. 4). Mean suspended sediment concentration was highly correlated in these streams while their contributing watersheds remained undisturbed. But streams in both patch-cut and clearcut watersheds contained higher mean concentrations of suspended sediment while their watersheds remained undisturbed--1.9 and 1.2, respectively, times the mean concentration in the control stream. These factors are used to estimate the changes in suspended sedimentation rate after the contributing watersheds of these streams came under management.

The amounts of sand and gravel carried along the streambed were also small. Bedload from the control watershed totaled 23 cubic feet per acre for 12 years for an annual average of nearly 2 cubic feet per acre (fig. 5). The accumulation was about half for the other two watersheds while they were undisturbed.

Maximum concentrations of sediment normally occur at the time of peak flow from winter storms. Measured peak concentrations seldom exceed 200 p.p.m. of suspended sediment. In the control stream, the maximum measured concentration (1,300 p.p.m.) occurred once during the storm in 1964-65, a storm with a likelihood of recurrence estimated at 100 years.

Sedimentation From Patch-cutting and Roads

Sedimentation increased in the fall of 1959 soon after the roads were completed. The first fall storm, on September 29, carried a peak concentration of 1,850 p.p.m.--250 times the expected concentration from this watershed in an undisturbed condition. This initial flush of sediment receded to about nine times the expected concentration 9 weeks later (Fredricksen 1965). For the next 2 years until the storm of December 1961, concentration increase remained at two to three times the expected undisturbed concentration (fig. 4). Only a modest rise in bedload sediment is evident for this period (fig. 5).

A landslide from the midslope road in late December 1961 again increased sedimentation (Fredriksen 1963). The mudflow resulting from this slide scoured over one-half mile of stream channel. Mean concentration for 1961-62 rose to 34 times the expected undisturbed concentration (fig. 4), and bedload sediment increased by 11 cubic feet per acre (fig. 5). An acre of bare soil left by the slide adjacent to the channel and debris deposited in the

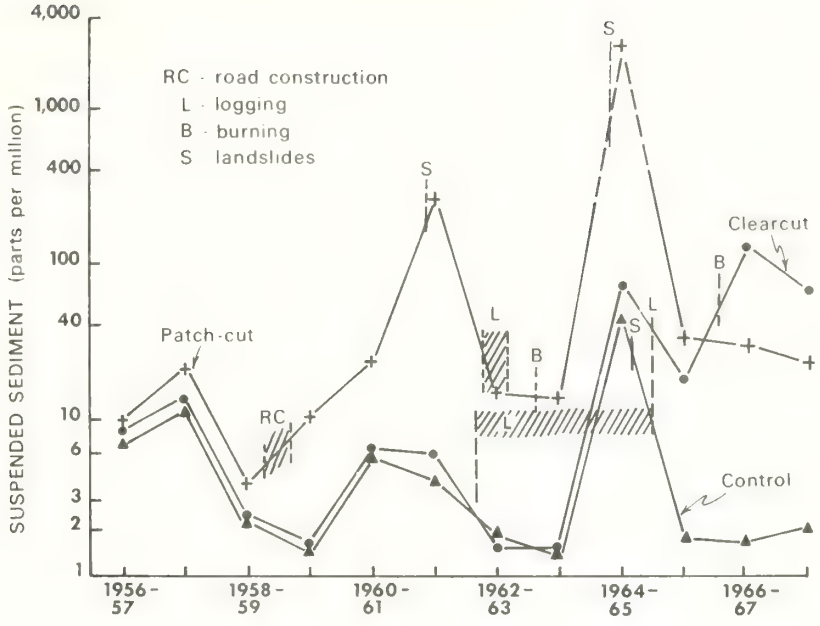

Figure 4.—Mean concentration of suspended sediment during the winter season high runoff period.

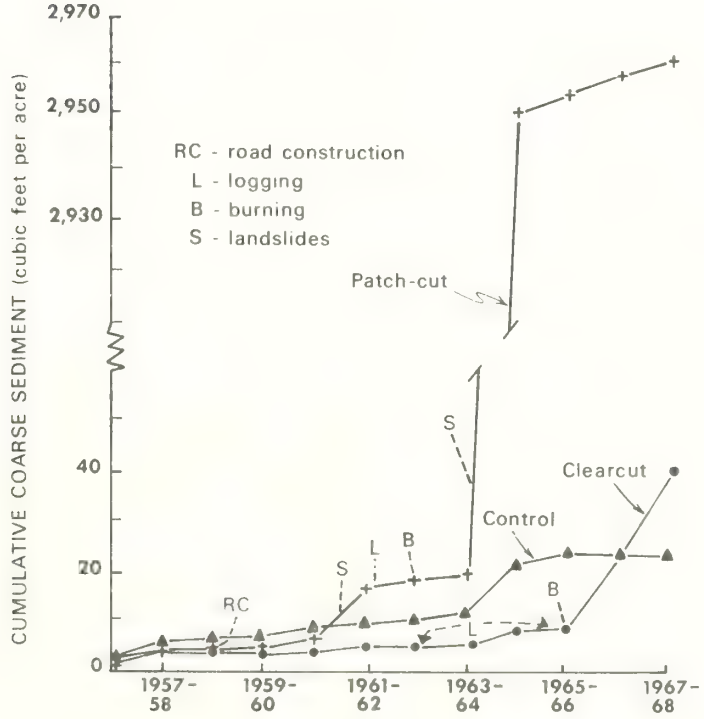

Figure 5.—Accumulated volume of coarse sediment trapped in catch basins.

channel became new sources that maintained the sedimentation during 1962-63 and 1963-64 at a level of five times the expected undisturbed concentration (fig. 4). Logging during the winter of 1962-63 and burning during the fall of 1963 caused no discernible rise in the sedimentation rate above the level created by the slide of December 1961.

The greatest sedimentation resulted from the landslide erosion and mudflows that scoured the stream channels in the patch-cut watershed during the largest storm to date, December 1964 (Fredriksen 1965). Mean concentration of 2,470 p.p.m. for 1964-65 was 34 times the expected undisturbed concentration (fig. 4). But a much larger proportion of the total sediment was moved as bedload (83 percent) during this year. The total volume of soil and rock deposited in the stream channel and covering the gaging station was 150 times the volume moved from the control watershed.

The estimated combined bedload and suspended sediment lost in this year was 70,200 tons per square mile. The estimated volume of soil from the landslides (37,600 cubic yards) is equivalent to 82,000 tons per square mile. Since a considerable volume of soil carried by the stream was not measured at the gaging site, the total estimated sediment loss of 70,200 tons per square mile for this year appears conservative (figs. 4 and 5).

Sedimentation rate remained elevated during the 3 years following the 1964 event. Sources of this sediment were subsoils bared by landslides, soil exposed along stream margins by mudflows, and soil deposited in the stream channel. Suspended sediment concentration remained at an average of nine times the expected undisturbed concentration (fig. 4), and bedload sediment accumulated at 4.6 times the rate in the control watershed during these 3 years (fig. 5).

Sedimentation From Clearcutting Without Roads

The first 2 years after logging began (1962-63 and 1963-64) were marked by little or no change in sedimentation (figs. 4 and 5). We attribute this to the filtering action of logging debris in the stream channel. Low sedimentation rates prevailed until landslides during the storm of January 1965 brought an estimated 800 cubic yards of soil and rock into the stream channel. Source areas of this material are indicated in figure 1. Although a modest rise in suspended sediment concentration was noted, compared with the expected undisturbed concentration, most of the fine sediment and nearly all the coarse sediment remained in the stream channel trapped behind logging debris.

Burning after completion of logging in October 1966 consumed all of the fine logging debris in the stream channel. Soil and rock in the channel, released by the fire, became a primary source of sediment. Soil exposed by the fire on the hillside slopes (table 1) was an additional source of sediment. These combined sources increased sedimentation during 1966-67 and 1967-68. Mean suspended sediment concentrations were 67 and 28 times the undisturbed level in the 2 respective years (fig. 4). Volume of coarse sediment increased to almost 30 cubic feet per acre for the 2 years compared with less than 0.1 cubic foot per acre from the control watershed.

Sediment Loss From the Patch-cut, Clearcut, and Control Watersheds

Soil loss from these watersheds is related to the type of management on the three watersheds (table 3). In the patch-cut watershed with 25 percent of the area clearcut and 6 percent in forest roads, total sediment yield for the 1960-68 period

Table 3.--*Mean annual soil loss from the three watersheds*

Watershed and means of transport	Yield		Relative yield	Soil loss
	1960-68	1963-68		
	Tons per square mile			*--Inches--*
Control:				
Suspended load	36	46	1.0	0.0006
Bedload	37	47	1.0	.0006
Total load	73	93	1.0	.0012
Clearcut without roads:				
Suspended load	--	195	4.2	.0027
Bedload	--	112	2.4	.0015
Total load	--	307	3.3	.0042
Patch-cut with roads:				
Suspended load	1,430	--	39.0	.0200
Bedload	6,550	--	178.0	.0900
Total load	7,980	--	109.0	.1100

was 109 times the loss measured from the control watershed. It is important that 99 percent of the soil was lost during the 2 years that landslides occurred, and 82 percent of this was bedload (table 4). Soil loss from the clearcut watershed *without* roads was only 3.3 times the loss from the control watershed (table 3), and two-thirds of this was suspended sediment (table 4). Nearly 70 percent of the soil was lost after burning. Mean annual sediment loss of 7,980 tons per square mile from the patch-cut watershed with roads was 26 times the loss of 307 tons from the clearcut watershed without roads.

DISCUSSION

Forest roads have been recognized as a major factor contributing to sedimentation of streams in the western Cascades (Dyrness 1967a, Rothacher and Glazebrook 1968). The relative yield data in table 3 emphasize the importance of secondary logging roads and the lesser importance of clearcutting on sedimentation in the steep headwater streams of this study. This study indicates that timber harvest operations involving high-lead cable yarding to a system of logging roads may increase sediment in streams draining these areas by two to 150 times the amount from undisturbed watersheds in any one year. These increases may average more than 100 times the undisturbed condition over a period of years.

By far the greatest soil loss was associated with landslides and the scouring action of high-velocity mudflows which often pass down the stream channels following a landslide. In fact, 97.7 percent of the sediment yield (table 4) from the patch-cut watershed occurred during the winter season of 1964-65 when 32 landslides occurred during a storm with a return interval estimated at 100 years. An additional 1.3 percent of the sediment yield occurred during an earlier landslide event in 1961-62. Landslides associated with forest roads moved the largest volume of soil. These landslides occurred most often where roads intersected stream channels. Clearcutting apparently had a much smaller influence on the occurrence of landslides.

Table 4.--*Distribution of total sediment yield during selected subperiods of the treatment phase of the clearcut and patch-cut watersheds*

Treatment and period of measurement	Suspended sediment	Bedload sediment	Total sediment
	Tons per square mile		
Clearcut watershed:			
Undisturbed, 1956-62	130	100	230 -
Harvest, 1962-64	9	5	14 (0.8%)
Harvest and landslides, 1964-66	470	70	540 (29.5%)
After burning, 1966-68	680	590	1,270 (69.7%)
Mean annual, 1962-68	195 (64%)	112 (36%)	307 (100%)
Patch-cut watershed:			
Undisturbed, 1956-59	130	80	210 -
Roads only, 1959-61	120	40	160 (0.2%)
First landslide--roads only, 1961-62	700	220	920 (1.3%)
Harvest and burning, 1962-64	80	40	120 (.2%)
Second landslide, 1964-65	11,700	58,500	70,200 (97.7%)
After second landslide, 1965-68	240	190	430 (.6%)
Mean annual, 1959-68	1,430 (18%)	6,550 (82%)	7,980 (100%)

Sources for the remaining 1.0 percent of the yield reported in table 4 (710 tons per square mile) arose from the newly constructed roads and sediment sources created by landslides--i.e., exposed subsoils on landslide areas, disturbed stream channels, forest road repair activities, and bare soil along stream margins for the 7 years when there were no landslides. These sediment sources maintained the suspended sediment concentration at an annual average level five times greater than the expected concentration of an undisturbed watershed (fig. 4).

Dyrness (1967a), from a much larger sample of landslide events following the 1964 storm on the H. J. Andrews Experimental Forest, also concluded that landslides were more frequent adjacent to forest roads. He found landslides slightly more frequent in logged areas compared with areas in green timber and that they occurred most frequently on slopes steeper than 60 percent. Dyrness points out that

> it should be borne in mind that in an area such as the Andrews Experimental Forest, where slopes are steep and a large portion is underlain by soft, deeply weathered pyroclastic rocks, the stage is set for extensive mass movements during high rainfall periods whether or not a disturbance is a factor. Therefore, it is perhaps often true that man's activities accelerate the occurrence of

> mantle failure events in an already unstable area, rather than contribute in any significant way to this basic instability. In other words, disturbance may cause some small and, by itself, insignificant change which is nonetheless sufficient to upset the tenuous equilibrium and trigger mass soil movement [a landslide event].

One not so surprising result was the relatively small soil loss attributable to surface erosion phenomena. Although surface runoff is seldom observed in the Experimental Forest on undisturbed areas, it is conceivable that changes in the soil surface, such as logging compaction and severe burning, could affect infiltration of water. However, in the clearcut watershed in 1962-63 and 1963-64, the initial effect of skyline logging had little or no influence on the sedimentation rate. There was also no significant increase in the prevailing sedimentation rate resulting from logging and burning in the clearcut areas of the patch-cut watershed. Mean concentration of suspended sediment did increase two to three times during 1959-60 and 1960-61 mainly as the result of surface erosion on 10.5 acres of cut- and fillslopes that remained after the completion of road construction. This sedimentation rate was small compared with sedimentation following landslide erosion.

Most of the sedimentation from these watersheds occurred during winter season periods of intense storm runoff. The three periods of extensive erosion by landslides in the experimental watershed occurred in conjunction with major storm runoff events characterized by very rapidly rising streamflow. Concentration of water in the soil must reach a maximum at the time of rapid stream rise. The three storm events were generated by the combined effects of rain and melting snow (Fredriksen 1963, 1965). Two other rainfall-induced runoff events have caused mass movements of soil in the Experimental Forest in the past 17 years. This short-term record indicates a short recurrence period of 3 to 4 years for these storms (Fredriksen 1965).

One other study reports sediment yields from forest land in the western Cascades of Oregon. Anderson (1954) estimated erosion potential of the upper McKenzie River drainage, including the H. J. Andrews Experimental Forest, at 110 to 140 tons per square mile per year. This estimate, which includes only suspended sediment yield, was made on the basis of 6.1 percent of the drainage in recent clearcuts and 0.1 percent of the area in roads. Mean annual suspended sediment yields from our study of 40 and 200 tons per square mile, respectively, for the undisturbed and clearcut watersheds are in the same order of magnitude as Anderson's estimates for the undisturbed and clearcut condition. As he indicated, sediment production may be far above the average where land use is heavy. Therefore, it is not surprising that average annual suspended sediment yield of 1,430 tons per square mile from the patch-cut watershed with 6 percent of the area in forest roads exceeds Anderson's estimate by one order of magnitude. Silen and Gratkowski (1953) estimated that roads disturb approximately 6 percent of the forest area under management when harvest is by patch-cut logging compared with 0.1 percent estimated by Anderson.

CONCLUSIONS

Although this report is limited to one set of three watersheds and a relatively short period of time, it clearly provides an estimate of sedimentation that can and does occur in the western Cascades. Where topography in this province is steep (valley sideslopes and drainage headwalls greater than 60 percent) and where soils

are naturally unstable (derived predominantly from tuff and breccia parent material), landslides are the major source of stream sedimentation. Their occurrence is more frequent where logging roads intersect stream channels. Slide-producing storms occur in this province at 3- to 4-year intervals and must be considered in harvesting plans.

This study suggests that we can expect a minimal deterioration in water quality arising from sedimentation where disturbance from road construction is minimized by reduction of midslope road mileage through the use of specially designed yarding systems. Where midslope roads must be constructed across steep sideslope or headwall areas, all knowledge available to the engineer should be used to stabilize roads. In the logging operation, every effort should be made to minimize disturbance to the streambed by keeping slash and debris out of the streams.

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Rothacher, Jack S., Dyrness, C. T., and Fredriksen, Richard L.
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_____ and Glazebrook, Thomas B.
1968. Flood damage in the National Forests of Region 6. USDA Forest Serv. Pacific Northwest Forest & Range Exp. Sta., 20 pp., illus.

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Silen, Roy R., and Gratkowski, H. J.
1953. An estimate of the amount of road in the staggered-setting system of clearcutting. USDA Forest Serv. Pacific Northwest Forest & Range Exp. Sta. Res. Note 92, 4 pp., illus.

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The mission of the PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION is to provide the knowledge, technology, and alternatives for present and future protection, management, and use of forest, range, and related environments.

Within this overall mission, the Station conducts and stimulates research to facilitate and to accelerate progress toward the following goals:

1. Providing safe and efficient technology for inventory, protection, and use of resources.
2. Development and evaluation of alternative methods and levels of resource management.
3. Achievement of optimum sustained resource productivity consistent with maintaining a high quality forest environment.

The area of research encompasses Oregon, Washington, Alaska, and, in some cases, California, Hawaii, the Western States, and the Nation. Results of the research will be made available promptly. Project headquarters are at:

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The FOREST SERVICE of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

USDA FOREST SERVICE RESEARCH PAPER PNW-105

SITKA SPRUCE -- a bibliography with abstracts

FIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION
EST SERVICE, U.S. DEPARTMENT OF AGRICULTURE

1970
PORTLAND, OREGON

FOREWORD

This bibliography contains references to world literature on Sitka spruce (*Picea sitchensis* (Bong.) Carr.) published through 1967. A subject matter index appears on pages 234-249, and a list of scientific and common names of tree and plant species mentioned is on pages 250-251. References are listed alphabetically by author.[1/]

Abstracts are given for many references. A large number are author abstracts used verbatim or condensed to include a minimum of essential detail. New abstracts were written where appropriate, often excerpting references to Sitka spruce from works dealing with more general subjects. Many abstracts were adapted or taken directly from "Forestry Abstracts," and special thanks are extended to Christopher Swabey, Director, Commonwealth Agricultural Bureaux Organisation, Oxford, for permission to reproduce this material. In compiling the bibliography, the most useful sources of references were "Forestry Abstracts" and "Bibliography of Agriculture," not only in locating references but also in providing title translations of foreign literature. Special effort was made to include the large body of British literature resulting from extensive plantings of Sitka spruce in the British Isles--an important source of information sometimes overlooked by American foresters.

Sincere appreciation is extended to reviewers who pointed out references not found by the compilers, and to the many librarians and others who provided reference material and helped in the preparation of this bibliography.

We would appreciate learning of additional articles on Sitka spruce not included here.

[1/] Publications listed herein are not available from the Pacific Northwest Forest and Range Experiment Station unless issued by the organization. Requests for reprints should be addressed to the author cited.

USDA FOREST SERVICE
RESEARCH PAPER PNW-105

SITKA SPRUCE --

A Bibliography With Abstracts

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1970

PACIFIC NORTHWEST
FOREST AND RANGE EXPERIMENT STATION
Forest Service, U.S. Department of Agriculture
Portland, Oregon

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2. _____
1909. Alaska's timber resources. Lumber Rev. 19(23): 18.

3. _____
1915. Logging in Alaska. Timberman 16(4): 48, illus.

Describes logging of Sitka spruce (referred to as Menzies spruce) in Alaska.

4. _____
1928. Seed soaked in sea water remain good. Forest Worker, Nov., p. 8.

5. _____
1932. Pacific coast spruce-hemlock area preserved. J. Forest. 30: 1020.

A tract of 1,400 acres in the Sitka spruce-western hemlock type has been set aside as the Quinault Natural Area. The tract contains some of the finest specimens of Sitka spruce to be found in the few remaining stands of old-growth timber.

6. _____
1942. Alaskan spruce for national defense. Amer. Forest. 48: 354-355, illus.

7. _____
1944. Popular misconceptions refuted in kiln-drying tests on Sitka spruce at Vancouver laboratories. Brit. Columbia Lumberman 28(12): 72-73.

Describes the effect of various kiln schedules on strength properties of Sitka spruce. With proper schedules, kiln-drying does not impair strength.

8. _____
1955. Canadian seeds used in Welsh forests. Brit. Columbia Lumberman 39(9): 34, illus.

Twice as many Sitka spruce trees are planted in Wales as any other species. The spruce grows well on the highlands, being hardy and resistant to exposure.

9. _____
1957. Alaska's logging operations pose unusual conditions. Timberman 58(12): 98.

10. _____
1957. Massenauftreten der Sitkalaus. [Mass outbreak of *Neomyzaphis abietina*.] Holz-Zentralbl. 83(70/71): 903-904. [In German.]

11. _____
1959. Canadian building timbers. Wood 24(8): 322-325, illus.

12. _____
1962. Sitka spruce named Alaska State tree. J. Forest. 60: 370.

On February 28, 1962, the Governor of Alaska signed a bill designating Sitka spruce as Alaska's official State tree.

13. _____
1962. B. C. Sitka spruce excels in Coventry Church. Brit. Columbia Lumberman 46(7): 76-77, illus.

Sitka spruce was used for the decorative inner canopy of the roof of the nave. In Great Britain, B.C. Sitka spruce has been widely used in aircraft and boatbuilding, and for highly stressed components in ladders, agricultural machinery, and vehicle bodies. For its resonance it finds favor with the makers of pianos and stringed instruments of all kinds.

14. _____
1964. Liability of trees on peat to wind-throw. Scot. Forest. 18(1): 38-43.

15. _____
1965. Alaska timber sales: Tongass National Forest sale volume 8.7 billion board feet. Forest Ind. 92(10): 64-65, illus.

A sale of 8,750 million board feet of timber was offered by the USDA Forest Service. The stand is estimated to contain about 44 percent western hemlock and 56 percent Sitka spruce, with small amounts of other species.

16. _____
1967. Target: 75 million seedlings by 1975. Brit. Columbia Lumberman 51(10): 40, illus.

The Forest Service officially opened a major forest nursery at Koksilah which will concentrate on growing Sitka spruce and western hemlock and will be capable of producing 7 million seedlings each year.

17. Aaron, J. R.
1957. Conifer barks as a source of tannins for the leather industry. Scot. Forest. 11(2): 72-76.

Analysis of 31 samples of Sitka spruce bark from trees grown in Great Britain showed an average tannin content of 17.5 percent. Percentage yield from dominant trees was higher than from suppressed trees. Yield was higher when bark was handpeeled than when bark was removed mechanically or chemically.

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1963. An interim report on field trials of treated and untreated round fencing timber. *In* Report on forest research for the year ended March 1962. Great Brit. Forest. Comm., pp. 133-137. London: H. M. Stationery Office.

19. Abdurahman, N., Dutton, G. G. S., McLardy, D. M., and others.
1964. Hemicelluloses of black spruce, Sitka spruce, ponderosa pine, and Douglas-fir. Tappi 47: 812.

Chlorite holocelluloses of each of the four woods were extracted with alkali and the hemicelluloses separated into fractions rich in "xylan," "galactoglucomannan," and "glucomannan." The characteristics of the extracts made from the different woods are compared.

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1954. Lokale Douglasovervejelser. [Douglas-fir in Denmark.] Dansk Skovforen. Tidsskr. 39(1): 1-60. [In Danish.]

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1940. An illustrated flora of the Pacific States, Washington, Oregon, and California. Vol. 1, ed. 2, 538 pp., illus. Stanford: Stanford Univ. Press.

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1947. Practical British forestry. Ed. 2, 394 pp., illus. London: Oxford Univ. Press.

Describes briefly the silviculture of Sitka spruce in Britain.

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Describes Sitka spruce planted in the Aleutian Islands in 1805 by the Russians and discusses the natural treelessness of the Aleutians.

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1966. Nutrient experiments with Sitka spruce. 76 pp., illus. (B.S. in Forestry thesis on file at Univ. Brit. Columbia, Vancouver.)

25. Ahrens, Von E.
1964. Untersuchungen über den Gehalt von Blättern und Nadeln verschiedener Baumarten an Kupfer, Zink, Bor, Molydbän und Mangan. [The content of Cu, Zn, B, Mo, and Mn in foliage of various tree species.] Allg. Forst- und Jagdzeit. 135(1): 8-16. [In German. English summary.]

Analyses of chemical elements in the foliage of several tree species, including Sitka spruce, as related to site, season, and other factors.

26. Ainslie, J. R.
1941. Timbers used in the construction of aeroplanes. Wood 6: 60-63, illus.

The species most commonly used in aircraft construction are ash and Sitka spruce. The material characteristics required for each part of the plane are discussed; the timbers now in use are given, and others that should be suitable are suggested.

27. Alaska University.
1967. The Kodiak economic community. Alaska, review of business and economic conditions. Univ. Alaska Inst. Soc., Econ., Government Res. 8 pp., illus.

Afognak Island, the smaller islands around it, and the northeast tip of Kodiak Island have valuable stands of Sitka spruce. Tree quality is lower than in southeast Alaska, and the stands are very heavily stocked. There are 270,000 acres of commercial forest land on the Archipelago. Plans and possibilities for commercial development are described.

28. Aldhous, J. R.
1959. Control of cutworm in forest nurseries. Forestry 32(2): 155-165.

Experiments were made to investigate the effect of BHC, DDT, aldrin, and dieldrin on cutworms (*Agrotis segetum*) and the phytotoxicity of these chemicals to Sitka spruce seedlings. A spray containing 3 pounds aldrin per acre (as a 30-percent miscible oil) or 1½ pounds dieldrin per acre (as a 15-percent miscible oil) gave excellent control of *A. segetum* larvae and did no damage to the seedling crop. Both insecticides were applied in 100 gallons water per acre.

29. _____
1959. Polythene bags for movements of forest nursery stock. Empire Forest. Rev. 38(1): 65-76.

Polyethylene bags were tested in England to reduce drying of nursery stock during storage and transport. Sitka spruce seedlings lifted beginning in mid-November and stored up to 6 months survived outstandingly well after planting.

30. _____
1960. A preliminary experiment on conifer seedbeds with 2, 6-dichlorobenzonitrile. Fifth Brit. Weed Contr. Conf. Proc. 1960: 617-624.

The material, worked into the top 2-3 inches of conifer seedbeds at 1 or 2 pounds per acre (active principle), completely controlled annual weeds from the time of application until mid-July, when it was applied as a wettable powder 8, 4, or 2 weeks before the plots were sown in early April or early May. The number and height of Sitka spruce seedlings was seriously reduced by applications of 2 pounds per acre and by some, but not all, applications of 1 pound; on plots treated with 1 pound per acre 4 or 8 weeks before sowing, weed control was good and Sitka spruce seedlings were undamaged. Applications of one-half pound per acre had little effect on crop or weeds. Surface applications also had little effect on crop or weeds. (From author's summary.)

31. _____
1961. Experiments in hand-weeding of conifer seedbeds in forest nurseries. Weed Res. 1(1): 59-67.

32. _____
1962. A survey of Dunemann seedbeds in Great Britain. Quart. J. Forest. 56(3): 185-196.

Describes results obtained from raising seedlings in Dunemann seedbeds as compared with results obtained with mineral seedbeds. Includes recommendations for the construction and operation of the beds.

33. _____
1962. Simazine--a weedkiller for forest nurseries. *In* Report on forest research for the year ended March 1961. Great Brit. Forest. Comm., pp. 154-165. London: H. M. Stationery Office.

34. _____
1962. Provenance of Sitka spruce: an account of the nursery stage of experiments sown in 1938. *In* Report on forest research for the

year ended March 1961. Great Brit. Forest. Comm., pp. 147-154. London: H. M. Stationery Office.

Reports the first 3 years' growth of 12 provenances collected between latitudes 61° and 43° N. from the northwest coast of America. Height growth increased as latitude decreased, especially in the range 61° to 49°, the taller provenances having the longer growing period; root-collar diameter and seedling weight did not vary with latitude of origin so clearly. The time of cessation of growth in late summer varied by up to 3 months, the last provenances to stop growing being damaged by frost. (From author's summary.)

35. _____ 1964. The effect of paraquat, 2, 6-dichlorothiobenzamide and 4-amino 3, 5, 6-trichloropicolinic acid ('Tordon') on species planted in the forest. Seventh Brit. Weed Contr. Conf. Proc. 1964(1): 267-275.

36. _____ 1964. Cold storage of forest nursery plants. An account of experiments and trials; 1958-63. Forestry 37(1): 47-63.

Sitka spruce seedlings were found suitable for storage from February until late May. Seedlings may be stored until August if surplus seedlings are being held over. Plants must be fully dormant when lifted, must not be put into storage until any rain or dew has dried off them, and should be stored in polythene bags.

37. _____ 1965. Bitumen mulches. *In* Report on forest research for the year ended March 1964. Great Brit. Forest. Comm., pp. 15-16. London: H. M. Stationery Office.

Bitumen mulch sprayed on seedbeds 3 to 4 weeks after sowing depressed germination of Sitka spruce drastically. For transplants, light and heavy application of bitumen between or over rows had no significant effect on survival or growth.

38. _____ 1965. Chemical control of weeds in the forest. Great Brit. Forest. Comm. Leafl. 51, 20 pp., illus.

Selective control of herbaceous and young broadleaved woody weeds can be accomplished with 2,4,5-T or a mixture of 2,4-D and 2,4,5-T, if spraying is done after conifer shoots have ceased elongation and formed buds. Sitka spruce is relatively resistant to sprays applied after mid-August.

39. _____ 1965. Fertilizer damage to transplants. *In* Report on forest research for the year ended March 1964. Great Brit. Forest. Comm., p. 16. London: H. M. Stationery Office.

Experiments at three nurseries with seedlings transplanted in the late spring showed Sitka spruce seedlings were unaffected by double the standard application of potassic superphosphate. *Abies procera* and *Picea abies* seedlings showed marked browning of foliage.

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1966. Paraquat as a pre-emergence spray for conifer seedbeds. *In* Report on forest research for the year ended March 1965. Great Brit. Forest. Comm., pp. 133-140. London: H. M. Stationery Office.

In experiments in 1962-64, preemergence sprays of paraquat did not affect most of the commonly sown conifers including Sitka spruce. The control of weeds achieved with paraquat at 0.5 pound active ingredient per acre was sometimes better and sometimes poorer than that following sprays of vaporizing oils. Postemergence sprays killed all conifer species under test, but pines and spruces took several weeks to react to postemergence sprays. (From author's summary.)

41. _____
1966. The effect of paraquat, 2, 6-dichlorothiobenzamide and 4-amino 3, 5, 6-trichloropicolinic acid ('Tordon') on species planted in the forest. *In* Report on forest research for the year ended March 1965. Great Brit. Forest. Comm., pp. 141-149. London: H. M. Stationery Office.

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1966. Bracken control in forestry with dicamba, picloram, and chlorthiamid. Eighth Brit. Weed Contr. Conf. Proc. 1966: 150-159.

43. _____
1967. Spacing in transplant lines. *In* Report on forest research for the year ended March 1966. Great Brit. Forest. Comm., p. 25. London: H. M. Stationery Office.

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1967. Review of research and development in forest nursery techniques in Great Britain, 1949-1966. Great Brit. Forest. Comm. Res. & Develop. Pap. 46, 11 pp.

45. _____
1967. Standards of sturdiness for forest tree plants. Great Brit. Forest. Comm. Res. & Develop. Pap. 36, 11 pp., illus.

Lists ratios of diameter to height for a range of species, including Sitka spruce.

46. _____
1967. Progress report on chlorthiamid ('Prefix') in forestry: 1962-1966. Great Brit. Forest. Comm. Res. & Develop. Pap. 49, 6 pp.

Sitka spruce was less affected by the herbicide chlorthiamid at 4 pounds per acre than most species tested.

47. _____ and Atterson, J.
1962. Nursery investigations. *In* Report on forest research for the year ended March 1961. Great Brit. Forest. Comm., pp. 19-27. London: H. M. Stationery Office.

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1963. Nursery investigations: storage of plants at low temperatures. *In* Report on forest research for the year ended March 1962.

Great Brit. Forest. Comm., pp. 20-22. London: H. M. Stationery Office.

49. _____ and Atterson, J.
1967. Weed control in the forest. *In* Report on forest research for the year ended March 1967. Great Brit. Forest. Comm., pp. 70-73. London: H. M. Stationery Office.

50. _____, Atterson, J., Brown, R. M., and others.
1967. Nursery investigations. *In* Report on forest research for the year ended March 1967. Great Brit. Forest. Comm., pp. 28-39. London: H. M. Stationery Office.

Describes work with Sitka spruce, including investigation of effects of density of sowing, date of sowing (on two provenances), bird repellents, fertilizer treatments, and simazine for weed control.

51. Allen, G. S.
1957. Storage behavior of conifer seeds in sealed containers held at 0° F., 32° F., and room temperature. J. Forest. 55: 278-281.

Indications are that Sitka spruce seed can be stored without appreciable loss of viability at 0° F. or 32° F. and presumably over a wider range of temperatures. Seed at fluctuating room temperature lost its viability over the 5- to 7-year test period.

52. Allen, George S.
1944. Management recommendations for the hemlock and associated forest types of the Juan de Fuca region of southwestern Vancouver Island. Brit. Columbia Forest Serv. Res. Note 11, 13 pp., illus.

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1962. The use of selective herbicides for conifer release. Sixth Brit. Weed Contr. Conf. Proc. 1962: 435-444.

A study was made in Scotland of damage sustained by different conifer species of varying ages after treatment with a mixture of low-volatile esters of 2,4-D plus 2,4,5-T (2/1 mixture) at three different dosages and in three diluents: water, water/oil, and oil. Plots were sprayed at monthly intervals beginning in September and ending in February. With water, no damage was sustained by any species at any dose. With water/oil, *Pinus sylvestris* and Sitka spruce sustained no serious damage at any dose. With oil, Sitka spruce was damaged at all dosages. Further trials of different formulations and volumes showed that in summer spraying Sitka spruce sustained no injury from 2,4,5-T at 20, 40, or 60 ounces per acre in 15 gallons or 150 gallons water.

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1967. Experiments with 2, 6-dichlorothiobenzamide (chlorthiamid) in planted areas of soft- and hardwoods. Eighth Brit. Weed Contr. Conf. Proc. 1967: 135-140.

55. Amchem Products, Inc.
1962. Oil-soluble amines of 2,4-D and 2,4,5-T for the control of woody plants and broadleaf weeds. Tech. Serv. Data Sheet, Ambler E-162, 15 pp. [Abstract in Weed Abstr. 11(6): 1847.]

56. American Forestry Association.
1956. These are the champs. Part 2. Amer. Forests 62(4): 33-40, illus.

The largest Sitka spruce reported is in Olympic National Park, Washington. It has a circumference of 51 feet, 6 inches, a height of 180 feet, and a crown spread of 50 feet.

57. American Plywood Association.
1966. U.S. Product Standard PS 1-66 for softwood plywood-construction and industrial together with DFPA grade marks. Tacoma, Wash. 28 pp., illus.

58. Andersen, H. E.
1955. Climate in southeast Alaska in relation to tree growth. USDA Forest Serv. Alaska Forest Res. Center Sta. Pap. 3, 11 pp., illus.

Rainfall in southeast Alaska is probably excessive for optimum tree growth as high rainfall tends to cause an excess of ground water. Best sites are well drained. Low temperatures during the growing season may limit tree growth as shown by the preponderance of high site classes on south slopes and decrease of average site index in the northern section. A compilation of climatic data for southeast Alaska is included.

59. _____
1955. Clearcutting as a silvicultural system in converting old forests to new in southeast Alaska. Soc. Amer. Forest. Proc. 1955: 59-61.

The present stand in southeast Alaska is a decadent climax with heavy cull. The goal of forest management is an even-aged stand composed of approximately equal volumes of western hemlock and Sitka spruce.

60. _____
1955. Girard form class comparisons for three major species in southeast Alaska. USDA Forest Serv. Alaska Forest Res. Center Tech. Note 26, 2 pp.

The average form class of Sitka spruce and western hemlock was respectively 76.4 and 75.8 for 32-foot logs and 82.4 and 82.2 for 16-foot logs. The difference between the species is not significant for either subclimax sawtimber or climax pulp timber, and their mean may be considered as 76 for 32-foot and 82 for 16-foot logs.

61. _____
1956. Cubic-foot volume tables for spruce and hemlock poletimber. USDA Forest Serv. Alaska Forest Res. Center Tech. Note 29, 1 p.

Presents gross cubic-foot volume of peeled wood from a 1-foot stump to a 4-inch top for poles in 6-, 8-, and 10-inch d.b.h. classes and total heights between 20 and 110 feet.

62. _____
1956. The problem of brush control on cutover areas in southeast Alaska. USDA Forest Serv. Alaska Forest Res. Center Tech. Note 33, 2 pp.

A dosage of 54 pounds of crystals per acre of NH_4 sulfamate caused defoliation of nearly all brush. Many hemlock seedlings died but Sitka

spruce proved more resistant. As costs were high and there was much resprouting, other methods of control should be tried.

63. _____ and Weisgerber, J. E.
1956. Use of long-log scaling tables in southeast Alaska. USDA Forest Serv. Alaska Forest Res. Center Tech. Note 32, 2 pp.

Long-log board-foot tables based on Scribner Decimal C rule were made for water scaling logs longer than 42 feet. These were based on a study which indicated that the average taper of western hemlock and Sitka spruce logs in southeast Alaska was 1 inch per 6 feet of log length.

64. Andersen, K. F.
1954. Gales and gale damage to forest with special reference to the effects of the storm of 31st January, 1953, in the northeast of Scotland. Forestry 27: 97-121 plus 1 plate.

Describes storm damage to Sitka spruce and associated species.

65. Anderson, J. P.
1918. Plants of southeastern Alaska. Iowa Acad. Sci. Proc. 1918(25): 427-449.

66. Anderson, Jacob Peter.
1959. Flora of Alaska and adjacent parts of Canada. 543 pp., illus. Ames: Iowa State Univ. Press.

67. Anderson, James R.
1925. Trees and shrubs. Food, medicinal, and poisonous plants of British Columbia. 165 pp., illus. Victoria, B.C.: Dep. Educ.

68. Anderson, M. L.
1930. A case of "damping-off" induced by the use of wood-ashes as a manure on seed-beds. Scot. Forest. J. 44(1): 7-16 plus 2 graphs.

69. Anderson, Mogens.
1951. Balancen I blandingsbevoksninger af rød-og Sitka-gran. [The balance in mixed plantations of Norway and Sitka spruce.] Skovforen. Tidsskr. 36(1): 1-44, illus. [In Danish.]

Describes the effect of light, winter temperatures, drought, soil, position, elevation, damage by wind, and disease on the balance between Sitka spruce and Norway spruce in a Danish plantation.

70. Anderson, R. T.
1937. Pruning green branches of conifers. Quart. J. Forest. 31(1): 29-31, illus.

71. Andrews, H. J., Cowlin, R. W., Moravets, F. L., and Meyer, W. H.
1935. Pulpwood resources of western Oregon and western Washington. USDA Forest Serv. Pacific Northwest Forest & Range Exp. Sta. Res. Note 17, 6 pp. plus 12 tables and 5 figs.

72. Andrews, I. H.
1949. Zinc hydrosulphite treatment of groundwood. Tappi 32: 286-288.

Gives values of improved brightness for various treatment rates and temperatures of ground wood from western hemlock, Sitka spruce, and balsam fir.

73. Andrews, L. R.
1956. B. C.'s timber industry today. Brit. Columbia Lumberman 40(11): 40-48; 40(12): 40-44, illus.

74. Annand, J. F.
1912. The annual summer meeting and tour of the Royal English Arboricultural Society, Perth, July 29th to August 2nd, 1912. Quart. J. Forest. 6: 303-328, illus.

Several specimens of Sitka spruce were viewed during the tour.

75. Appleton, J. B.
1939. The Pacific Northwest: a selected bibliography, 1930/39. 455 pp. Portland, Oreg.: Northwest Regional Council.

Lists completed research in the natural-resource and socioeconomic fields with an annotated list of in-progress and contemplated research.

76. Aranda, Martin J., and Coutts, J. R. H.
1963. Micrometeorological observations in an afforested area in Aberdeenshire: rainfall characteristics. J. Soil Sci. 14(1): 124-133.

Rainfall was measured at an open site and under Sitka spruce, pine, and heather. Between 50 and 60 percent of the rain penetrated each of the canopies. Variations in the percentage penetration are associated with the area of foliage to be wetted and with the aggregate amount and intensity of the rainfall. (From author's summary.)

77. Archer, C. F.
1952. Kiln-drying schedules for British Columbia woods. Can. Dep. Resources & Develop., Forest. Br., Forest Prod. Lab. Div. V-1012, 18 pp.

The wood of all western spruces is practically indistinguishable and can be seasoned under the same conditions. Schedules are given.

78. Armit, D.
1964. Natural nurseries. Brit. Columbia Forest Serv. Forest Res. Rev. (year ending March 1964), p. 26.

Reports on a continuing project to produce Sitka spruce wildlings by manipulating the canopy and forest floor and then comparing these wildlings with seedlings grown in standard nursery beds. Conclusions: 3+0 is superior to 2+0 as a planting size; fertilization does not improve growth of the wildlings; 2+0 standard nursery stock is superior to 2+0 natural nursery stock.

79. _____
1964. Sitka spruce spacing trial. Brit. Columbia Forest Serv. Forest Res. Rev. (year ending March 1964), pp. 29-30.

80. _____
1967. Sitka spruce spacing trial. Brit. Columbia Forest Serv. Forest Res. Rev. (year ending March 1967), p. 67.

Reports on Sitka spruce spacing trials established in 1961 west of Kalum Lake. Spacings range from 6 by 6 to 15 by 15 feet. Measurements of average height in 1966 indicated no significant differences related to spacing or block effects. Crown closure is expected on the 6-by 6-foot plots and possibly on the 9-by 9-foot plots by the next measurement in 1971.

81. Armstrong, F. H.
1935. Further tests on the effect of progressive decay by *Trametes serialis* Fr. on the mechanical strength of the wood of Sitka spruce. Forestry 9: 62-64.

A close relationship was found between reduction in resistance to compression and the progress of decay as measured by the loss in dry weight. Advance of fungal attacks was indicated by an increase in brittleness and irregularity of fracture.

82. _____
1947. The strength of home-grown timber pit-props. Forestry 21(1): 43-76.

Results of strength tests on European and Japanese larch, Norway spruce, Scotch pine, Corsican pine, Douglas-fir, and Sitka spruce showed the spruce to be below average in strength.

83. Arno, Stephen F.
1967. Interpreting the timberline: an aid to help park naturalists to acquaint visitors with the subalpine-alpine ecotone of western North America. 206 pp., illus. San Francisco: U.S. Dep. Int. Nat. Park Serv. Western Reg. Office.

Describes Sitka spruce at timberline throughout its range.

84. Arthur, Joseph Charles.
1934. Manual of the rusts in United States and Canada. 438 pp. plus supplement, illus. Lafayette, Indiana.

The following rusts are found on Sitka spruce: *Melampsorella cerastii*, *Chrysomyxa ledicola*, and *Peridermium parksianum*.

85. Aspinall, G. O., Laidlaw, R. A., and Rashbrook, R. B.
1957. The glucomannans from Sitka spruce *Picea sitchensis*. J. Chem. Soc. (London), pp. 4444-4448.

Hemicellulose fractions composed of *d*-mannose and *d*-glucose residues have been isolated from Sitka spruce holocellulose. A methylated glucan and a methylated glucomannan have been prepared therefrom, hydrolysis affording the corresponding 2 : 3 : 6-trimenthyl ethers. It is concluded that both glucan and glucomannan are linear polysaccharides composed of B-1 : 4-linked sugar residues. (From author's summary.)

86. Atterson, J.
1965. Magnesium deficiency in pines. *In* Report on forest research for the year ended March 1964. Great Brit. Forest. Comm., pp. 16-17. London: H. M. Stationery Office.

A symptom of magnesium deficiency (yellowing) of Sitka spruce in nursery beds was removed by spraying seedbeds with Epsom salt solution. A more promising source of magnesium is magnesium ammonium phosphate.

87. _____
1965. Weed control in the nursery. *In* Report on forest research for the year ended March 1964. Great Brit. Forest. Comm., pp. 17-19. London: H. M. Stationery Office.

88. _____
1966. Amelioration of forest sites. (1) Nutrition. (a) Forest nutrition in Scotland and northern England. *In* Report on forest research for the year ended March 1965. Great Brit. Forest. Comm., pp. 21-25. London: H. M. Stationery Office.

89. Austin, R. C., and Strand, R. F.
1960. The use of slowly soluble fertilizers in forest planting in the Pacific Northwest. J. Forest. 58: 619-627, illus.

Describes response of planted Sitka spruce seedlings to fertilization.

90. Ayers, H. B.
1899. Washington Forest Reserve. *In* Nineteenth annual report 1897/98. Part 5. Forest Reserves. U.S. Geol. Surv., pp. 283-313, illus.

91. Babb, M. F.
1959. Ornamental trees and shrubs for Alaska. Univ. Alaska Agr. Exp. Sta. Bull. 24, 39 pp., illus.

92. Baerg, Harry J.
1955. How to know the western trees: pictured keys to the native and cultivated trees found growing in the Rocky Mountains and westward, with suggestions and aids for their study. 170 pp., illus. Dubuque, Iowa: W. C. Brow Co.

93. Bailey, Harold E., and Bailey, Virginia Long.
1941. Forests and trees of the western National Parks. U.S. Dep. Interior Nat. Park Serv. Conserv. Bull. 6, 129 pp., illus.

94. Bailey, L. H.
1948. The cultivated conifers in North America. Ed. 2, 404 pp., illus. New York: Macmillan Co.

95. Bailey, Virginia L., and Bailey, Harold E.
1949. Woody plants of the western National Parks; containing keys for the identification of trees and shrubs. Amer. Midland Natur. Monogr. 4, 274 pp., illus.

96. Baker, F. S.
1949. A revised tolerance table. J. Forest. 47: 179-181.

Sitka spruce is rated very tolerant to tolerant on a relative scale of very tolerant, tolerant, intermediate, intolerant, and very intolerant.

97. Baker, Frederick S.
1929. Effect of excessively high temperatures on coniferous reproduction. J. Forest. 27: 949-975, illus.

98. _____
1950. Principles of silviculture. 414 pp., illus. New York: McGraw-Hill Book Co.

99. Baker, William J.
1929. Moisture reabsorption study of kiln-dried Sitka spruce. Timberman 30(8): 86.

100. Bakke, A. R. F.
1960. Douglaslusa funnet pa sorlandet. [The Cooley spruce gall aphid found on the South Coast.] Norsk Skogbruk 6(1): 12, illus. [In Norwegian. English summary.]

The aphid *Adelges cooleyi* = (*Chermes cooleyi*) has been recorded on Douglas-fir and Sitka spruce near Grimstad on the south coast of Norway. This is the first record on Sitka spruce in Norway.

101. Baldwin, E.
1967. A fertiliser trial on deep peat. Scot. Forest. 21(4): 229-231.

Sitka spruce and lodgepole pine were planted on deep peat in 1956 and each seedling received 2 ounces of ground mineral phosphate. A subsequent fertilizer treatment in 1961 containing 14 percent nitrogen, 2.5 percent phosphorus, and 16.5 percent potassium improved growth for a period of time apparently related to the rate of application. Annual shoot growth started to fall off appreciably 4 years after fertilizer application of 500 pounds per acre.

102. Balfour, F. R. S.
1932. The history of conifers in Scotland and their discovery by Scotsmen. Conifers in cultivation. Conifers Conf. Roy. Hort. Soc. Rep., Nov. 10-12, 1931, pp. 177-211, illus.

Sitka spruce was introduced into Britain by David Douglas. Many specimens over 100 feet tall are reported, and occasional trees have reached 130 feet. During the war, spruce timber was imported under the name "silver spruce."

103. Balfour, R. M., and Kirkland, R. C.
1963. The effect of creosote on populations of *Trypodendron lineatum* breeding in stumps. *In* Report on forest research for the year ended March 1962. Great Brit. Forest. Comm., pp. 163-166. London: H. M. Stationery Office.

Incidence of attack by *T. lineatum* was low on Sitka stumps whether creosote-treated or not, and successful emergence of adults was rare compared with that from logs.

104. Bandekow, Richard J.
1947. Present and potential sources of tannin in the United States. J. Forest. 45: 729-734.

Sitka spruce bark contains about 25 percent tannin but it has not been used by the tanning industry.

105. Bannan, M. W.
1963. Cambial behaviour with reference to cell length and ring width in Picea. Can. J. Bot. 41: 811-822, illus.

Interrelations between frequency of multiplicative divisions, cell length, and ring width in *Picea* largely resembled those in *Pinus strobus*. Maximum cell length was observed in *P. sitchensis*, and minimum in *P. engelmannii*, which also had fewest multiplicative divisions (the other species studied were *P. glauca* and *P. mariana*). Orientation of the partition in pseudo-transverse division tended to be unidirectional, but reversal of direction of tilt occurred after varying intervals. The connection of these phenomena with the development of spiral grain is discussed.

106. Barrett, John W. (ed.)
1962. Regional silviculture of the United States. 610 pp., illus. New York: Ronald Press.

Presents an area-by-area guide to the biological, physical, and economic aspects of the Nation's continental forest regions and their effect on efficient and productive silviculture practices. Describes silviculture of the major forest type groups of the Pacific Northwest, both in the coastal subzone and the humid transition zone. Description for each group includes the typical site where the group occurs, its place in ecological succession, growth rates, rotations, cultural practices, reforestation, and susceptibility to damage.

107. Bartels, H.
1958. Untersuchungen uber die Hitzetoleranz der Koniferensamen. [Investigations on the heat tolerance of conifer seeds.] Forstwiss. Cent. 77(9/10): 287-294. [In German.]

Gives heat tolerance of seeds of several conifers, including Sitka spruce.

108. Bartholomew, C. R.
1955. Effect of an agricultural spray on forest trees. Quart. J. Forest. 49(2): 139-140.

109. Barton, Lela V.
1930. Hastening the germination of some coniferous seeds. Amer. J. Bot. 17(1): 88-115.

Germination percent was improved by stratifying Sitka spruce seed for 2 months at 5° C.

110. _____
1954. Effect of subfreezing temperatures on viability of conifer seeds in storage. Boyce Thompson Inst. Contrib. 18(1): 21-24, illus.

Seeds of five conifer species, including Sitka spruce, were stored in canvas bags at subfreezing temperatures of approximately -4°, -11°, and -18° C. for 3 years. Storage temperature of -18° C. was found best for maintaining viability. Deterioration was most rapid at -4° C.

111. Bauer, Franz.
1956. Heideaufforstung in Dänemark. [Heathland afforestation in Denmark.] Holz-Zentralbl. 32(136): 1647-1648, illus. [In German.]

Describes two trial plots near Ulvborg, Jutland, on poor, mostly shallow, sandy soils where groups of various species, now 17-23 years old, were established by hole planting under shelter of a first forest generation of *Pinus mugo* and *P. mugo* var. *rostrata*. Height growth and general appearance are discussed and partly tabulated. *Larix japonica*, *Picea abies*, and *P. sitchensis* are considered most promising, and *Abies alba* is recommended on biological grounds.

112. Bauger, E.
1961. Forelopig produksjonstabell for Sitkagran på Vestlandet. [Preliminary yield table for Sitka spruce in W. Norway.] Medd. Vestlandets Forstl. Forsøkssta. 35: 123-167. [In Norwegian. English summary.]

Table is based on data from permanent sample plots in pure stands, none of which exceed 44 years of age.

113. _____ and Smitt, A.
1960. Et treslags-og proveniensforsøk på Stad. [An experiment on tree species and provenances on Stad.] Medd. Vestlandets Forstl. Forsøkssta. 34: 59-121 plus 40 photos, diagram. [In Norwegian. English summary.]

Sitka spruce gave the most promising results of several species tried on a windswept peninsula in west Norway. It was able to withstand wind when growing on good, deep soils with sufficient moisture. An Alaska provenance gave better results than one from British Columbia.

114. Bauger, Eivind, and Orlund, Arnstein.
1962. Undersøkelser etter kvisting I treslagene Sitkagran, *Abies grandis*, hemlock, gran og Thuja. [A study of pruned trees of Sitka spruce, *Abies grandis*, western hemlock, Norway spruce, and *Thuja plicata*.] Medd. Vestlandets Forstl. Forsøkssta. 36: 172-197, illus. [In Norwegian. English summary.]

A study of 2,016 knots led to the following conclusions: (1) pruning (either green or dry, usually at about 2 m.) did not cause rot or other defects of practical importance; (2) pruning season (autumn, winter, and late spring) had no effect; (3) stub length tended to increase with branch diameter, especially for hemlock; (4) the time taken for stub healing tended to increase with stub length and to decrease with increasing knot diameter. Results under (3) and (4) are so variable, however, that no reliable conclusions can be drawn.

115. Bavngaard, A.
1957. Negatieve grene. [Negative branches.] Dansk Skovforen. Tidsskr. 42(12): 601-634. [In Danish.]

Restates the author's theory that suppressed branches live at the expense of the tree as a whole, citing as supporting evidence examples from 17-year-old Sitka spruce.

116. Baxter, Dow V.
1942. Some resupinate polypores from the region of the Great Lakes, XIII. Mich. Acad. Sci., Arts, Lett. 27: 139-161, illus.

117. _____
1947. Occurrence of forest fungi in major forest types of Alaska. Pap. of Mich. Acad. Sci., Arts, Lett. for 1945, 31: 93-115, illus.

118. _____
1952. Pathology in forest practice. Ed. 2, 601 pp. New York: J. Wiley & Son. (Ed. 1, 1943, 618 pp.)

119. Baxter, D. V., and Varner, R. W.
1942. Importance of fungi and defects in handling Alaskan airplane spruce. Univ. Mich. Sch. Forest. Conserv. Circ. 6, 35 pp.

120. Beach, John E. G.
1939. The pruning of Scots pine and Sitka spruce. Scot. Forest. J. 53: 85-89.

Pruning should be done as soon as possible after plantation reaches the pole stage. Pruning higher than 30 feet is not likely to prove economical. The best tools for pruning are pole saws up to 12 to 15 feet and above that light ladders and hand saws.

121. Bean, W. J.
1916. Stomata on the leaves of Sitka spruce. Quart. J. Forest. 10: 237-238.

It was noted that cone-bearing branches of Sitka spruce occasionally have stomata on the ventral leaf surface.

122. _____
1951. Trees and shrubs hardy in the British Isles. Vol. II, 664 pp., illus. London: John Murray.

123. Beaton, J. D., Moss, A., MacRae, I., and others.
1965. Observations on foliage nutrient content of several coniferous tree species in British Columbia. Forest. Chron. 41: 222-236.

In one set of Sitka spruce samples, concentrations of N, P, K, Ca, Mg, and S in current needles were 1.15, 0.18, 0.82, 0.42, 0.09, and 0.14 percent, respectively.

124. Becking, Rudy W.
1956. Die naturlichen Douglasien-Waldgesellschaften Washingtons and Oregons. [The forest association of Douglas-fir in its natural

range in Washington and Oregon.] Allg. Forst- und Jagdzeit. 127(2/3): 42-56, illus. [In German. English summary.]

Sitka spruce is a principal tree species in the Fog Belt (*gaultherieto-Pseudotsugetum sitchensetosum*) association. Indicator plants are listed for high and low sites.

125. Begley, C. D., and Howell, R.
1960. Air seasoning softwoods at stump. Forestry 33(2): 187-202.

Presents a brief statistical analysis of some practical results obtained from an experiment carried out with Sitka spruce thinnings between 1952 and 1957. Some savings in extraction costs can be expected from reduction in weight. Rate of seasoning differs with different seasons of felling and between peeled and unpeeled poles. Seasoning causes no serious deterioration in the quality of the timber for use as pit-props or boxwood. (Author's summary.)

126. Behrndt, G.
1961. Auftreten und Bekampfung der Sitkalaus im Fruhjahr 1961 im Privatwald des Weser-Ems-Raumes. [Occurrence and control of *Liosomaphis abietina* in private forests of the Weser-Ems region in spring 1961.] Allg. Forstzeitschrift 16(46): 659-661. [In German.]

In Sitka spruce plantations, Metasystox at 0.8 to 1 liter per hectare in 80 to 100 liters water, applied by knapsack sprayer to stands up to 3 meters tall, and to taller stands by helicopter, gave good control. Fogging with a lindane preparation was greatly hampered by wind and dew. Trees with stiff, blue-green foliage appeared to be more resistant than trees with green needles. In untreated areas, the outbreak was controlled by some disease. Costs of application are given.

127. Bejer-Petersen, B.
1962. Peak years and regulation of numbers in the aphid *Neomyzaphis abietina* (Walker). Oikos 13(1): 155-168, illus.

128. Belcher, Earl W., and Hitt, Robert G.
1965. Eastern tree seed laboratory twelfth annual report fiscal year 1965. USDA Forest Serv. Eastern Tree Seed Lab., 66 pp., illus.

Lists requirements for seed samples sent to the laboratory for testing; lists recommendations for testing; and contains sample forms and instructions for submitting samples. For Sitka spruce, stratification for 90 days is recommended; length of germination test is 20 days. A total of 122 days should be allowed for testing. Three-tenths of an ounce (10 g.) of seed should be submitted.

129. Bell, D. B.
1957. The relationship between height growth in conifers and the weather. J. Oxford Univ. Forest. Soc. 4(5): 11-14, illus.

130. Bell, W. L.
1958. Frost damage to Sitka spruce seedbeds, Pubble Nursery. Forest. Northern Ireland 1(4): 37-40.

Seedbeds suffer greatly from both early and late frosts at this nursery in northern Ireland. The degree of injury is closely related to density of sowing.

131. Benson, G. T.
1930. The trees and shrubs of western Oregon. Vol. II, 170 pp., illus. Dudley Herb. Contrib. Stanford: Stanford Univ. Press.

132. Benson, H. K., Thompson, T. G., and Wilson, G. S.
1923. The chemical utilization of wood in Washington. Univ. Wash. Eng. Exp. Sta. Ser. 19, 160 pp., illus.

133. Benzian, B.
1953. Nutrition problems in forest nurseries. Rothamsted [England] Exp. Sta. Rep. 1952: 42-45.

134. _____
1959. Nutrition problems in forest nurseries. J. Sci. Food Agr. 10(12): 637-644.

Results from many small-plot experiments in different nurseries and seasons, with Sitka spruce as the main test crop, have shown that it is safe to use commercial fertilizers (Nitro-Chalk, ammonium sulphate, superphosphate, and potassium chloride) in seedbeds and transplant beds. In short-term experiments, testing a range of composts and uncomposted organic materials, with and without additional fertilizer, effects were related to the major plant nutrients present. Interim results of several other experiments are discussed.

135. _____
1963. Comparison of Sitka spruce and Norway spruce in forest nurseries. Rothamsted [England] Exp. Sta. Rep. 1962: 54-55.

Results in nursery plots split between the two species were closely comparable during 1959-62, except for slight color differences caused by K deficiency. Both showed large and consistent height responses to N and P, and well-defined deficiencies were caused by lack of N, K, and Mg. In July 1962, however, after a cold, dry spring, Norway spruce transplants developed a severe red "scorch," associated with dressings of potassium chloride and ammonium sulphate whereas Sitka spruce on the same plots remained green and healthy.

136. _____
1966. Effects of nitrogen and potassium concentration in conifer seedlings on frost damage. Rothamsted [England] Exp. Sta. Rep. 1965: 58-59.

137. _____
1967. Manuring young conifers: experiments in some English nurseries. Fertilizer Soc. London Proc. 94: 5-37.

Manuring experiments dating from 1945 show that Sitka spruce and other conifers are sensitive to soil reaction and prefer acid soils. Soluble fertilizers were generally more efficient than compost on a poor, leached soil, but compost plus fertilizers was most satisfactory. Preliminary results from slow-release fertilizers were promising.

138. _____
1967. Picea sitchensis. Isobutylidene diurea for conifer seedlings. Rothamsted [England] Exp. Sta. Rep. 1966/67: 43-44, plus table.

Describes tests with seedlings in the nursery using IBDU, a slow-acting N fertilizer. Two sizes of granules were used. Heavy rains may have favored IBDU over other formulations; more testing is needed.

139. _____ and Bolton, J.
1966. Calcium as a plant nutrient for Sitka spruce. Rothamsted [England] Exp. Sta. Rep. 1965: 62.

140. _____ and Ogborn, J. E. A.
1955. Nutrition problems in forest nurseries. Rothamsted [England] Exp. Sta. Rep. 1954: 47-50.

Describes interim results of several experiments involving Sitka spruce.

141. _____ and Warren, R. G.
1956. Nutrition problems in forest nurseries: needle tip-burn. Rothamsted [England] Exp. Sta. Rep. 1955: 49-50.

A symptom known as "needle tip-burn" in Sitka spruce transplants was diagnosed as a copper deficiency.

142. _____ and Warren, R. G.
1956. Copper deficiency in Sitka spruce seedlings. Nature 178(4538): 864-865.

Describes nutritional experiments designed to cure tip-burn of Sitka spruce seedlings by application of a foliar spray of copper sulphate. Seedling heights increased nearly 50 percent on sprayed plots. In another experiment, a compost of bracken and hop-waste resulted in complete disappearance of deficiency symptoms. This result was attributed to copper content in the hop-waste, presumably from copper boilers used to boil the hops.

143. Benzian, Blanche.
1954. Nutrition problems in forest nurseries. Summary report for 1953. *In* Report on forest research for the year ended March 1954. Great Brit. Forest. Comm., pp. 38-50. London: H. M. Stationery Office.

144. _____
1956. Nutrition problems in forest nurseries. *In* Report on forest research for the year ended March 1955. Great Brit. Forest. Comm., pp. 71-72. London: H. M. Stationery Office.

Addition of phosphate to nursery soil resulted in substantial increase in height of Sitka spruce seedlings. Effects of soil treatments with formalin and chloropicrin are also discussed.

145. _____
1964. Nutrition experiments in forest nurseries: comparison of Sitka spruce and Norway spruce. *In* Report on forest research for the year ended March 1963. Great Brit. Forest Comm., pp. 87-88. London: H. M. Stationery Office.

146. _____
1965. Nutrition experiments in forest nurseries: potassium manuring of Sitka spruce seedlings. *In* Report on forest research for the year ended March 1964. Great Brit. Forest. Comm., pp. 87-88. London: H. M. Stationery Office.

147. _____
1965. Experiments on nutrition problems in forest nurseries. 2 vols. Great Brit. Forest. Comm. Bull. 37.

Reports on work carried out between 1945 and 1962 by a joint research effort between staff of the Rothamsted Experiment Station and the research branch of the Forestry Commission. Contains many results of experiments on the nutrition of many conifer species including Sitka spruce. Volume II gives tables relating to numerous experiments on the nutrition of various conifers including Sitka spruce.

148. _____, Bolton, J., and Mattingly, G. E. G.
1965. Nutrition experiments in forest nurseries: slow-release fertilizers for conifer seedlings. Rothamsted [England] Exp. Sta. Rep. 1964: 55-57.

Describes effects of phosphorus and potassium fertilizers on 1-year-old seedlings.

149. _____, Bolton, J., and Mattingly, G. E. G.
1966. Nutrition experiments in forest nurseries: slow-release fertilizers for conifer seedlings. *In* Report on forest research for the year ended March 1965. Great Brit. Forest. Comm., pp. 88-89. London: H. M. Stationery Office.

150. _____, Bolton, J., and Mattingly, G. E. G.
1967. Nutrition experiments in forest nurseries. *In* Report on forest research for the year ended March 1967. Great Brit. Forest. Comm., pp. 133-134. London: H. M. Stationery Office.

Describes results of a slow nitrogen fertilizer, isobutlidenediurea, on Sitka spruce seedlings in a forest nursery and continuation of an experiment comparing effects of potassium metaphosphate, potassic superphosphate, and potassium dihydrogen phosphate on growth of Sitka spruce seedlings.

151. _____ and Freeman, S. C. R.
1967. Effect of "late-season" N and K top dressings applied to conifer seedlings and transplants, on nutrient concentrations in the whole plant and on growth after transplanting. *In* Report on forest research for the year ended March 1967. Great Brit. Forest. Comm., pp. 135-140. London: H. M. Stationery Office.

Dressing applied in September increased nutrient concentration at a stage when growth had nearly ceased. For seedlings of Sitka spruce and western hemlock, susceptibility to autumn frost was decreased by both N and K. After lining out, bud development was slightly accelerated and height growth at the end of the season slightly increased for most species.

152. Bergemann, J.
1955. Die Mykorrhiza-Ausbildung einiger Koniferen-Arten in verschiedenen Boden. [The development of mycorrhizae of some conifers in different soils.] Z. Weltforstwirt. 18(5/6): 184-202, illus. [In German. English summary.]

Compares growth of mycorrhizae on six conifer species, including Sitka spruce, grown in pot cultures with three soil types.

153. Berner, E., Jr.
1950. Chlorophyll production by young coniferous plants at different light intensities. Arbok, Univ. Bergen, 1949(1 Hefte), Naturvitnskapelig Rekke 6, 32 pp.

154. Berntsen, Carl M.
1954. Some results of chemical debarking on Sitka spruce, western hemlock, and red alder. USDA Forest Serv. Pacific Northwest Forest & Range Exp. Sta. Res. Note 104, 7 pp., illus.

Sodium arsenite painted on a sap-peeled girdle on spruce and hemlock during the growing season loosened bark sufficiently to allow peeling of large sections the following year. Breakage during felling was more severe for treated trees.

155. _____
1955. Seedling distribution on a spruce-hemlock clearcut. USDA Forest Serv. Pacific Northwest Forest & Range Exp. Sta. Res. Note 119, 7 pp., illus.

After clearcutting of a spruce-hemlock stand (Cascade Head Experimental Forest, Oregon), 160-milacre regeneration plots were established with five seedbed types: (1) rotten and decomposing wood, (2) mineral soil, (3) surface covered with slash, (4) heavy vegetation, (5) swampy ground. Examination 7 years after clearcutting showed spruce regeneration on 53 percent and hemlock on 44 percent of the plots. Best conditions were provided by (1) (97 percent stocked) and (2) (83 percent stocked); (5) was unstocked. There were more than twice as many seedlings on plots with a north aspect as on those with a south aspect. Accumulations of slash were found to retard growth of trees and other vegetation.

156. _____
1958. A look at red alder--pure and in mixture with conifers. Soc. Amer. Forest. Proc. 1958: 157-158.

157. _____
1960. Planting Sitka spruce and Douglas-fir on decayed wood in coastal Oregon. USDA Forest Serv. Pacific Northwest Forest & Range Exp. Sta. Res. Note 197, 5 pp., illus.

Four-year survival of Douglas-fir and Sitka spruce on both north and south aspects was the same whether seedlings were planted on mineral soil or on naturally occurring decayed wood. Height growth was as good (or better) on decayed wood as on soil. The decayed wood held moisture late into the summer, was a good medium for root growth, and discouraged competition from other plants. Planting on decayed wood in coastal Oregon is recommended where growing-season precipitation averages at least 10 inches.

158. _____
1961. Growth and development of red alder compared with conifers in 30-year-old stands. USDA Forest Serv. Pacific Northwest Forest & Range Exp. Sta. Res. Pap. 38, 20 pp., illus.

To help provide basic growth data for red alder and associated species, experimental plots were established during the period 1935-37 on the Cascade Head Experimental Forest, near the Oregon coast. Treatments were designed to illustrate potential growth of red alder as it occurs in pure stands at an early age. Growth of these alder stands was compared with growth of a stand thinned to pure conifer--Douglas-fir, Sitka spruce, and western hemlock.

159. Berry, James Berthold.
1964. Western forest trees; a guide to the identification of trees and woods for students, teachers, farmers, and woodsmen. 212 pp., illus. New York: Dover Publications.

160. Betts, H. S.
1929. The strength of North American woods. U.S. Dep. Agr. Misc. Pub. 46, 18 pp.

161. _____
1945. American woods: Sitka spruce. U.S. Dep. Agr. Forest Serv., 5 pp.

Gives briefly the description, nomenclature, distribution and growth, supply, production, properties, and principal uses of Sitka spruce.

162. Betts, Harold S.
1919. Timber: its strength, seasoning, and grading. 234 pp., illus. New York and London: McGraw-Hill Book Co.

163. Bevan, D.
1966. The green spruce aphis *Elatobium* (*Neomyzaphis*) *abietinum* (Walker) Scot. Forest. 20(3): 193-201, illus.

164. Bever, Dale N.
1954. Evaluation of factors affecting natural reproduction of forest trees in central western Oregon. Oreg. State Board Forest. Res. Bull. 3, 49 pp., illus.

165. Bialobok, Stefan, and Chylarecki, Henryk.
1965. Badania nad upwawa drzew pochodzenia w Polsee w warunkach srodowiska lesnego. [Investigations on the cultivation of exotic trees in forest conditions in Poland.] Arboretum Kornicki, Pozan 10: 211-277 plus 2 tables, 4 maps. [In Slovak. English summary.]

166. Bier, J. E.
1946. The relation of research in forest pathology to the utilization of overmature timber. The significance of brown pocket rot in Sitka spruce on the Queen Charlotte Islands. Brit. Columbia Lumberman 30(6): 54-55, 74, illus.

167. _____ and Foster, R. E.
1946. The relation of research in forest pathology to the preparation of forest inventories. I. Suggested aids for cruising overmature

stands of Sitka spruce on the Queen Charlotte Islands. Brit. Columbia Lumberman 30(4): 38-40, 64, illus.

168. _____ and Foster, R. E.
1946. The relation of research in forest pathology to the utilization of overmature timber. II. Significance of conk rot in Sitka spruce on Queen Charlotte Islands. Brit. Columbia Lumberman 30(5): 51-52, 65, illus.

169. _____ and Foster, R. E.
1946. The relation of research in forest pathology to the preparation of forest inventories. 2. The possibility of obtaining net volumes by grade when cruising overmature stands of Sitka spruce on the Queen Charlotte Islands. Brit. Columbia Lumberman 30(7): 52-53, 66, 68, illus.

170. _____, Foster, R. E., and Salisbury, P. J.
1946. Studies in forest pathology. IV. Decay of Sitka spruce on the Queen Charlotte Islands. Can. Dep. Agr. Tech. Bull. 56, 35 pp. plus 10 plates.

Reviews previous investigations and describes loss from decay, with particular emphasis on a disease known locally as pocket rot.

171. _____ and Nobles, Mildred K.
1946. Brown pocket rot of Sitka spruce. Can. J. Res. 24C(4): 115-120, illus.

A brown pocket rot of Sitka spruce occurs in stands on the Queen Charlotte Islands, B.C. The decay, the sporophore associated with it, and the cultural characters of the fungus are described. The causal fungus is described as *Lentinus kauffmanii* sp. n. by Dr. Alexander H. Smith, Univ. of Mich. (Author's summary.)

172. Binkley, Virgil W.
1965. Economics and design of a radio-controlled skyline yarding system. Pacific Northwest Forest & Range Exp. Sta. USDA Forest Serv. Res. Pap. PNW-25, 30 pp., illus.

An analysis of factors affecting time and costs of skyline logging in mature Sitka spruce and western hemlock on the Cascade Head Experimental Forest near Otis, Oreg.

173. Binns, W. O.
1961. Forest soils research in Scotland. *In* Report on forest research for the year ended March 1960. Great Brit. Forest. Comm., pp. 93-94. London: H. M. Stationery Office.

174. _____
1962. Some aspects of peat at a substrate for tree growth. Irish Forest. 19(1): 32-55.

Studies at 12 deep peat sites in Scotland and northern England show that needs of Sitka spruce and other conifers for additional P and K may be estimated from the total P and K contents of the upper layers of the peat.

175. _____
1965. Amelioration of forest sites. *In* Report on forest research for the year ended March 1964. Great Brit. Forest. Comm., pp. 21-22. London: H. M. Stationery Office.

176. _____
1966. Current fertilizer research in the forestry commission. Sixth Discussion Meeting, Edinburgh, Rep., 7 to 9 January. Forestry (Suppl.) 39: 60-64.

Pole-stage experiments have suggested that Sitka spruce is likely to respond to phosphorus on some mineral soils. Sitka spruce has not responded to nitrogen, though other species have. Trials on near-mature crops, following up Scandinavian work, will be started soon. (From author's summary.)

177. _____ and Atterson, J.
1967. Nutrition of forest crops. *In* Report on forest research for the year ended March 1967. Great Brit. Forest. Comm., pp. 48-53. London: H. M. Stationery Office.

Describes results of a demonstration of nutrient deficiencies on Sitka spruce and lodgepole pine. Describes 1966 results on permanent foliage sampling plots established to measure variations of nutrient concentrations in foliage.

178. _____ and Coates, A. E.
1966. Manuring of pole-stage crops. *In* Report on forest research for the year ended March 1965. Great Brit. Forest. Comm., pp. 25-26. London: H. M. Stationery Office.

Describes fertilizer experiments in south and central England and Wales.

179. _____ and Grayson, A. J.
1967. Fertilization of established crops: prospects in Britain. Scot. Forest. 21(2): 81-98.

Application of 88 pounds phosphorus per acre to three pole-stage Sitka spruce stands in Wales resulted in growth increases of 11 to 18 percent over a 7-year measurement period. Experiments on three other Welsh sites failed to increase growth because the primary limiting factor was poor drainage. In general, the Welsh work on pole-stage Sitka spruce indicates that nitrogen can be omitted over a wide range of sites.

180. Bishop, Daniel M., and Stevens, Mervin E.
1964. Landslides on logged areas in southeast Alaska. Northern Forest Exp. Sta. USDA Forest Serv. Res. Pap. NOR-1, 18 pp., illus.

Describes and tentatively analyzes landslides on timbered slopes of mountainous southeast Alaska. Vegetation below timberline is mainly western hemlock and Sitka spruce. Recent large-scale clearcut logging of timber has accelerated debris avalanches and flows on steep slopes.

181. Bjarnason, Hakon.
1951. A brief report on the reforestation of Iceland. Skograekt Rikisins. Reykjavik, 14 pp. [In English.]

Between 1899 and 1913, seed and seedlings of different species were introduced into Iceland and planted in the south, north, and northwest of the country. The growth of these species, including Sitka spruce, is discussed.

182. _____
1965. Um gróðurskilyrði og skógraekt. [Growing conditions and forestry.] Arsrit Skógraektarf. Íslands 1965: 5-12. [In Icelandic.]

183. _____
1967. Ferd til Skotlands og Bretlands 1966. [A short trip to Scotland and England in the spring 1966.] Ársrit Skógraektarf. Íslands 1967: 26-33, illus. [In Icelandic. English summary.]

184. Blair, Sir James Hunter.
1946. Frost damage to woodlands on Blairquhan Estate in April 1945. Scot. Forest. J. 60(1): 38-43.

Presents notes on damage caused by a severe frost (16° F.) following a mild winter and spring. The most extensive damage occurred in plantations of Sitka spruce. Damage varied from complete destruction to crippling; though most severe in frost hollows, it also occurred on sloping ground and even on knolls. Damage was most severe in the young plantations but is also apparent in trees up to 40 feet high and 20 years old. Effects of frost on several other species are described.

185. Blanc, L.
1961. Valeur papetiere, pour papier kraft, des bois resineux exotiques. [The suitability of exotic conifers for kraft paper pulp.] Rev. Forest. Franc. 13(8/9): 558-566, illus. [In French.]

Describes small-scale test of kraft paper made from the pulp of various exotics grown in France, including Sitka spruce, after various degrees of refinement, with graphs illustrating strength properties.

186. Bletchly, J. D., and Taylor, Jean M.
1964. Investigations on the susceptibility of home-grown Sitka spruce (*Picea sitchensis*) to attack by the common furniture beetle (*Anobium punctatum* Deg.). J. Inst. Wood Sci. 12 (May): 29-43, illus.

Describes the effect of the chemical composition and compression wood of Sitka spruce on the development of larvae inserted into blocks.

187. _____ and White, M. G.
1962. Significance and control of attack by the ambrosia beetle (*Trypodendron lineatum*) (Oliv.) (Col Scolytidae) in Argyllshire forest. Forestry 35(2): 139-163 plus 4 photos.

Damage to saw logs of Sitka spruce and other softwood species in Argyllshire forest by pinhole borers was studied and control measures were developed. Most damage was by the ambrosia beetle. Attack begins in April, reaches a peak in May, then declines rapidly and becomes of negligible importance after August. Trees felled between November and January are more susceptible, but few logs left at stump are attacked. Damage is much more widespread in logs stacked in the forests or at the mill. Control methods are discussed.

188. Blew, J. O., Roth, H. G., and Davidson, H. L.
1967. Preservative retention and distribution in several western conifers. Amer. Wood Preservers' Ass., 12 pp., illus.

Preservative retention of Sitka spruce from Oregon and Alaska was erratic but reasonably good. Spruce grown in Oregon performed better than that grown in Alaska.

189. Blokhuis, J. L. W.
1955. Gebruik van kunstmest in de bossen. [Use of artificial fertilizers in forestry.] Ned. Boschb.-Tijdschr. 27(7): 178-181. [In Dutch.]

Reports further progress on plots established in 1933-36. The favorable effect of Ca treatment on oak, Norway and Sitka spruce, and Douglas-fir, and its bad effect on Japanese larch were still visible.

190. Boe, K. N.
1966. Windfall after experimental cuttings in old-growth redwoods. Soc. Amer. Forest. Proc. 1965: 59-63.

191. Bollen, W. B., and Wright, Ernest.
1961. Microbes and nitrates in soils from virgin and young-growth forests. Can. J. Microbiol. 7: 785-792.

Penicillium spp. predominated in samples of forest soils except occasionally at depths of 3 inches, when *Mucor* and *Aspergillus* spp. were sometimes more abundant. Incubation for 30 days at 28° C. and 40 percent moisture capacity frequently increased the percent of *Mucor* as well as of *Penicillium* spp. *Mucor* spp. were consistently more predominant in soils associated with alder than in other coastal soils. The greatest concentration of N as NO_3 in unincubated soils was found in a young red alder stand. Samples of soil from stands of virgin coastal redwood showed no NO_3-N. Soils from stands of virgin Sitka spruce, however, showed considerable NO_3 content, which increased markedly with incubation. With few exceptions, bacteria and actinomycetes were most numerous in the F soil horizon. Incubation greatly increased these populations in most soils. (From author's summary.)

192. Bollen, Walter B., Chen, Chi-Sin, Lu, Kuo C., and Tarrant, Robert F.
1967. Influence of red alder on fertility of a forest soil, microbial and chemical effects. Forest Res. Lab. Oreg. State Univ. Res. Bull. 12, 61 pp., illus.

Describes microbial and chemical characteristics of the soil under adjoining stands of conifer (including Sitka spruce), alder, and mixed alder-conifer.

193. Bones, James T.
1961. Estimating spruce and hemlock D.B.H. from stump diameter. USDA Forest Serv. Northern Forest Exp. Sta. Tech. Note 51, 2 pp.

194. _____
1962. Relating outside- to inside-bark diameter at top of first 16-foot log for southeast Alaska Timber. USDA Forest Serv. Northern Forest Exp. Sta. Tech. Note 52, 2 pp.

Contains a table showing conversion factors for Sitka spruce, western hemlock, Alaska-cedar, and western redcedar, with information on the number and dimensions of sample trees measured.

195. _____
1963. Wood processing in Alaska, 1961. Northern Forest Exp. Sta. USDA Forest Serv. Resource Bull. NOR-1, 14 pp., illus.

Findings of a complete canvass of the primary wood processors of Alaska in 1961. Sitka spruce provided 46 percent of the volume of logs consumed by Alaskan wood processors.

196. _____
1963. Volume distribution by log position for southeast Alaska trees. Northern Forest Exp. Sta. USDA Forest Serv. Res. Note NOR-1, 2 pp.

197. Bongard, Heinrich G.
1833. Observations sur la vegetation de l'ile de Sitcha. [Observations of the vegetation of Sitka Island.] St. Petersburg Acad. Sci. Mem., Ser. 6, Sci. Math. Phys. Nat. 2: 119-177. [In French.]

Includes botanical description of Sitka spruce, page 164. Referred to as *Pinus sitchensis*.

198. Booth, H. A.
1940. The growing of Sitka spruce for pitprops. Quart. J. Forest. 34: 72-74.

Measurements of two Sitka spruce stands about 35 years old showed 1,150 and 1,100 poles per acre, with a volume inside bark of 3,929 and 3,817 cubic feet, respectively, corresponding to nearly 50,000 lineal feet of props per acre. The two stands were underthinned, and it is suggested that deliberate underthinning might be used to produce a large number of stems per acre and to improve quality resulting from closer growth rings. Sitka spruce is tolerant of poor soils and should be a desirable tree to grow on a short rotation for pitprops, if the site is within 50 miles of a colliery.

199. Borchers.
1952. Folgerungen aus den bisherigen Anbauergebnissen mit fremdländischen Holzarten im Gebiet des Landes Niedersachsen für die künflige waldbauliche Planung. [Conclusions to be drawn for future silvicultural planning from the results so far obtained in trials of exotic tree species in Niedersachsen.] Mitt. Deut. Dendrol. Ges. (Jb. 1951/52) 57: 68-81. [In German. English summary.]

Describes several plantations of various species, including Sitka spruce.

200. Bornebusch, C. H.
1937. Sommerplantning af Naaletraeer. [Summer planting of conifers.] Forstl. Forsøgsv. Danmark 14(2): 97-132, illus. [In Danish.]

201. _____
1941. Fremmede Naaletraeer paa Søllestedgaard revision; 1940. [Exotic coniferous trees on Søllestedgaard estate revised in 1940.] Forstl. Forsøgsv. Danmark 15(5), 32 pp. [In Danish. English summary.]

202. _____
1944. Godskning af planteskoler. [Manuring of nurseries.] Dansk Skovforen. Tidsskr. 29(2): 49-55. [In Danish.]

203. _____
1944. Opbevaring af Rødgran-og Sitkagranfrø. Foreløbige Forsøgsresultater. [Storage of Norway and Sitka spruce seed. Preliminary results of experiments.] Dansk Skovforen. Tidsskr. 29: 257-263, illus. [In Danish.]

Describes tests of seed storage. Best results came from seed stored at 4- to 8-percent moisture content in a dark, frost-free cellar. Such seed retained its viability unchanged for 2 years.

204. _____
1946. Sitka-Hvidgran-Bastarden. [The Sitka X white spruce hybrid.] Dansk Skovforen. Tidsskr. 31: 42-46. [In Danish.]

Sitka X white spruce hybrids are said to have existed in the Danish Forest Research Organization's nurseries as long ago as the end of the last century and to have been shorter branched but not inferior to pure Sitka in growth. Performance in relation to seed origin is discussed.

205. _____ and Ladefoged, Kjeld.
1940. Hvidgranens og Sitkagranens Dødelighed i Hede-og Klitplantager i 1938 og 1939. [Cold damage to white spruce and Sitka spruce in heath and dune plantations during 1938 and 1939.] Forstl. Forsøgsv. Danmark 15(4): 209-232, illus. [In Danish.]

During the winter of 1938-39, severe frost damage was observed on white spruce, Sitka spruce, and Douglas-fir. This was the result of an unusually high temperature in March (6.5° to 10° C. above the normal temperature) that was followed by very low April temperature--3.8° C. below zero. The cambial zone had commenced activity previous to the April frost and was severely injured.

206. Børset, O.
1967. Om bruk av eksotiske treslag i Norge. [The use of exotic trees in Norway.] Skogbrukets Skogind. Forsk. (Oslo), 18 pp. [In Norwegian.]

Chiefly reviews literature outlining the history of trials of exotics in Norway since 1739. The only exotic species of economic and practical importance is Sitka spruce.

207. Borthwick, A. W.
1909. Frost canker of *Picea sitchensis* (Trautv. et Mey.), the Menzies spruce. Roy. Bot. Gard. Notes (Edinburgh) 4(20): 263-265 plus plate LI.

208. Boullard, B.
1964. L'elagage des resineux: un commentaire s'appuyant sur des travaux recents. [The pruning of conifers: a commentary based on recent work.] Foret Privee, Paris 37: 5-17, illus. [In French.]

Supplies a practical guide to pruning, with commentary on experience with several conifer species, including Sitka spruce.

209. Boullard, Bernard.
1961. Etude d'une attaque '1' *Armillariella mellea*' (Vahl) Quel. sur l'epicea de Sitka: hiologie du parasite, moyens de lutte. [An attack of *Armillaria mellea* on Sitka spruce: biology of the parasite and control methods.] Rev. Forest Franc. 13(1): 16-24, illus. [In French.]

Describes an attack on a 15-year-old plantation of Sitka spruce in Normandy and discusses possible control measures; also briefly reviews the literature on the biology of the fungus.

210. Bowers, N. A.
1918. Filling the allies' rush order for airplane spruce. Eng. News-Rec. 81: 1023-1031.

211. Bowers, Nathan A.
1942. Cone bearing trees of the Pacific Coast. 169 pp., illus. New York and London: Whittlesey House, div. of McGraw-Hill Book Co.

Description, distribution, and general information about Sitka spruce.

212. _____
1956. Cone-bearing trees of the Pacific Coast. Ed. 5(rev.), 169 pp., illus. Palo Alto, Calif.: Pacific Books.

213. Bowman, Paul W.
1934. Pollen analysis of Kodiak bogs. Ecology 15(2): 97-100.

214. Boyce, J. S.
1923. Decays and discolorations in airplane woods. U.S. Dep. Agr. Bull. 1128, 51 pp., illus.

Discusses general wood specifications and the significance of many typical discolorations and decays in regard to the suitability of timber for aircraft construction. Sitka spruce is described as the most important wood used for this purpose.

215. _____
1929. Deterioration of wind-thrown timber on the Olympic Peninsula, Washington. U.S. Dep. Agr. Tech. Bull. 104, 28 pp., illus.

Following the January 29, 1921, windstorm, Sitka spruce deteriorated less rapidly than western hemlock and Pacific silver fir, but more rapidly than Douglas-fir and western redcedar. Most of the loss for the first three seasons was due to ambrosia beetles and blue stain in the sapwood. Decay became more important after the fourth season, and by the summer of 1926, the sapwood of all species had been virtually destroyed. Considerable Sitka spruce heartwood had been rotted. By the summer of 1926, total loss in Sitka spruce was 46.3 percent of the board-foot volume and 41.7 percent of the cubic-foot volume.

216. _____
1930. Decay in Pacific Northwest conifers. Yale Univ. Osborn Bot. Lab. Bull. 1, 51 pp., illus.

Presents information in a nontechnical style for landowners, lumbermen, foresters, and forestry students, enabling them to recognize the decays of commercially important softwoods in the Pacific Northwest and apply this knowledge in cruising and scaling. (From author's explanation.)

217. Boyce, John S.
1961. Forest pathology. Ed. 3, 572 pp., illus. New York: McGraw-Hill Book Co.

218. Bradley, R. T.
1967. Thinning control in British woodlands. Great Brit. Forest. Comm. Booklet 17, 32 pp., illus.

Provides a guide to the volume to be removed in thinning of pure even-aged stands or, with suitable modifications, in thinning of woods of mixed species and/or uneven age. Sitka spruce is included.

219. _____
1967. Thinning experiments and the application of research findings in Britain. Fourteenth IUFRO-Kongress Pap., Munchen. 9(sect. 25, no. 6): 242-249.

Discusses thinning research techniques and their limitations and the current status of thinning research with Sitka spruce in Britain.

220. _____, Christie, J. M., and Johnston, D. R.
1966. Forest management tables. Great Brit. Forest. Comm. Bull. 16, 218 pp., illus.

Includes general yield class curves, production class curves, thinning control tables, production forecast tables, and normal yield tables for Sitka spruce. Supplement No. 1, published March 1967, includes normal yield tables for yield classes 80 and 60.

221. _____, Christie, J. M., and MacKenzie, A. M.
1962. Mensuration. *In* Report on forest research for the year ended March 1961. Great Brit. Forest. Comm., pp. 65-69. London: H. M. Stationery Office.

222. Brandstrom, Axel.
1918. Possibilities of future airplane spruce production in the Pacific Northwest. Univ. Wash., Forest. Club Annu. 6: 15.

223. Brayshaw, T. C.
1960. Key to the native trees of Canada. Can. Dep. Forest. Bull. 125, 43 pp., illus.

224. Brazier, J. D.
1967. Timber improvement. I. A study of the variation in the wood characteristics in the young Sitka spruce. Forestry 40(2): 117-128.

A study of variation in some wood characteristics in Sitka spruce indicated a similar pattern of within-tree variation in density, tracheid length, and grain inclination for both selected and average final crop trees. There was an appreciable variation in these characteristics between trees of comparable ages, indicating the potential for improvement by selection. There was a reduction in density and some increase in grain inclination, but no difference in tracheid length in vigorous compared to average-growth trees at comparable ages. There was no evidence that selection for above-average density would have an adverse effect on tracheid length; it tends to favor trees having a high minimum wood density and, to a limited extent, wood with narrow cells. (From author's summary.)

225. Briegleb, P. A.
1940. Spruce-hemlock forest shows prodigious growth. USDA Forest Serv. Pacific Northwest Forest & Range Exp. Sta. Res. Note 31: 1-2.

Data from 11 plots established on the Cascade Head Experimental Forest near Otis, Oreg., showed that at age 89 a stand of spruce-hemlock had a volume of 22,530 cubic feet or 262 cords per acre. Species composition was 54 percent hemlock, 45 percent Sitka spruce, and 1 percent Douglas-fir.

226. Brind, Janet E.
1965. Some studies of the effect of partial sterilization on the soil micropopulation. *In* Blanche Benzian (ed.), Experiments on nutrition problems in forest nurseries. Great Brit. Forest. Comm. Bull. 37(1): 206-209.

227. Brit, G. de, and O'Carroll, N.
1967. Group dying of Sitka spruce, and its relationship with *Rhizina undulata* and fire sites. Fourteenth Congr. Int. Union Forest. Res. Organ. Proc. (Munich) Part V. 24: 494-500.

228. British Columbia Forest Service.
1936. Volume, yield, and stand tables for some of the principal timber species of British Columbia. Brit. Columbia Forest Serv., 53 pp., illus.

229. _____
1948. Growth studies. Brit. Columbia Forest Serv. Rep. 1947: 17-18.

For the purpose of determining the total age of older trees when a ring count is made at a known height above the ground, an analysis was made of hemlock, spruce, and cedar seedlings growing on cutover areas. The results are given in a table showing total height in feet at ages from 1 to 10 years for hemlock and spruce on both good and poor soils, and for western redcedar on average sites.

230. _____
1949. Volume tables. Brit. Columbia Forest Serv. Rep. 1948: 11-17.

Site-class volume tables for Douglas-fir, western hemlock, western redcedar, coast balsam fir, and Sitka spruce, in British Columbia.

231. _____
1950. Number of years necessary to grow to height of ring count. Brit. Columbia Forest Serv. Rep. 1949: 31.

232. _____
1962. Sitka spruce spacing trial. Brit. Columbia Forest Serv. Forest Res. Rev. 1961/62: 20.

Describes establishment of a spacing trial begun in 1961 with spacings of 6 by 6, 9 by 9, 12 by 12, and 15 by 15 feet.

233. _____
1962. Basic taper curves for the commercial softwood species of British Columbia. Brit. Columbia Forest Serv., unpaged, 21 figs.

234. _____
1966. Butt-taper tables for coastal tree species. Brit. Columbia Forest Serv. Forest Survey Note 7, 12 pp., illus.

Includes a butt-taper table for Sitka spruce from 0.5 to 5.0 feet above ground level.

235. _____
1966. Net volume (loss) factors. Brit. Columbia Forest Serv. Forest Survey Note 8, 80 pp., illus.

Presents factors used to reduce gross volumes (reported at close, intermediate, or rough utilization standards) by decay only or by a combination of decay, waste, or breakage to arrive at a realistic net volume.

236. British Standards Institution.
1955. Nomenclature of commercial timbers including sources of supply. 144 pp. London: Waterlow & Sons.

237. Britton, Nathaniel Lord, and Shafer, John Adolph.
1908. North American trees; being descriptions and illustrations of the trees growing independently of cultivation in North America, north of Mexico and the West Indies. 894 pp., illus. New York: Henry Holt & Co.

238. Brockman, C. Frank.
1949. Trees of Mount Rainier National Park. 49 pp., illus. Seattle: Univ. Wash. Press.

Sitka spruce is of such limited occurrence in the park it is unlikely that visitors will find it here. A few isolated specimens have been reported at low elevations in the North Puyallup and Carbon River valleys near the west boundary.

239. Broughton, J. A. H.
1962. Properties of 30- to 37-year-old Sitka spruce timber. Great Brit. Dep. Sci. & Ind. Res. Forest Prod. Res. Bull. 48, 24 pp., illus.

A general account of studies on the fundamental properties of Sitka spruce from many sites in the United Kingdom. Outlines methods of field sampling, laboratory testing, and examining the properties in relation to end use.

240. Brown, H. P., and Panshin, A. J.
1934. Identification of the commercial timbers of the United States. 223 pp., illus. New York and London: McGraw-Hill Book Co.

241. _____, Panshin, A. J., and Forsaith, C. C.
1949. Textbook of wood technology. Vol. I, 652 pp., illus. New York: McGraw-Hill Book Co.

242. Brown, J. M. B.
1965. Forest ecology: fall-off in growth of Sitka spruce in South Wales. *In* Report on forest research for the year ended March 1964. Great Brit. Forest. Comm., p. 47. London: H. M. Stationery Office.

243. _____ and Bovan, D.
1966. The great spruce bark beetle, *Dendroctonus micans*, in northwest Europe. Great Brit. Forest. Comm. Bull. 38, 41 pp. plus 34 plates.

Describes the life history of the insect. *D. micans* attacks several spruces, but Sitka spruce appears more susceptible than Norway spruce. Consequently, outbreaks occur mostly where Sitka spruce has been widely planted (Jutland, northwest Schleswig-Holstein).

244. Brown, James, and Nisbit, John.
1894. The forester. Vol. 1, 629 pp., illus. Edinburgh and London: William Blackwood & Sons.

245. Brown, L. L.
1921. Canadian Sitka spruce: its mechanical and physical properties. Can. Dep. Int. Forest. Br. Bull. 71, 39 pp.

Sitka spruce from the Queen Charlotte Islands is stronger than that grown on the mainland in southern British Columbia by approximately 3 to 14 percent. Density is not readily apparent because of the similar color of springwood and summerwood and the gradual transition from one to the other. Strength increases from the pith outward. Strength of small, clear pieces of Sitka spruce increases very rapidly when dried below the fiber-saturation point, which is about 31 percent moisture, based on dry weight of the wood. Increase in moisture above the fiber-saturation point does not influence the strength of the wood. Curves are presented by which the strength of any piece of clear Sitka spruce can be closely estimated from its density.

246. Brown, W., Falkehag, S. I., and Cowling, E. B.
1967. Molecular size distribution of lignin in wood. Nature 214(5086): 410-411, illus.

247. Browne, J. E.
1962. Standard cubic-foot volume tables for the commercial tree species of British Columbia, 1962. Brit. Columbia Forest Serv., 107 pp.

Presents 24 cubic-foot volume tables for 15 commercial tree species, including tables for immature and mature Sitka spruce.

248. Bruce, David, and Court, Arnold.
1945. Trees for the Aleutians. Geogr. Rev. 35(3): 418-423.

Briefly describes the climate of the Aleutian Islands, the slow spread of forest on Kodiak Island, and the attempts of the American army to plant trees in the Aleutians during the war. The only species which survived after a year was Sitka spruce.

249. Bruce, Mason.
1960. National Forest in Alaska. J. Forest. 58: 437-442.

General description of Sitka spruce stands in Alaska. Sitka spruce makes up 29 percent of the gross timber volume.

250. Brückner, E.
1952. Anbauversuche mit fremdlandischen Holzarten in Wuchsgebiet des Erzgebirges. [Trials with exotics in Erzgebirge region.] Wald 2(2): 55-57. [In German.]

251. Bryan, J.
1963. Pulp and paper: effect of fibre form on pulp properties. Great Brit. Dir. Forest. Prod. Res. Rep., Princes Risborough 1962: 40-42.

Pulp was prepared from each of 21 annual rings in a single internode of a Sitka spruce tree. Preliminary results of tests are discussed.

252. _____ and Doman, L. S.
1940. Fire resistance--the comparative resistance to fire of various species of timber. Wood 5(1): 19-23, illus.

Sitka spruce was tested along with 77 other species for inflammability, flame penetration, rate of burning, fire resistance, and the results were compared. Fire resistance was found to be "low."

253. _____ and Pearson, F. G. O.
1955. The quality of Sitka spruce grown in Great Britain. Empire Forest Rev. 34(2): 144-153, illus.

An account of an investigation into the "quality," as measured by specific gravity, of Sitka spruce from six plantations in Great Britain. Within the tree, specific gravity tended to be high near the pith, fell to a minimum about 15-20 rings from the pith, and then increased steadily to the cambium layer. This pattern occurred in every tree examined from each site. Strength in compression was generally proportional to specific gravity, with the addition of a superimposed trend of increasing specific strength from pith to cambium, so that the high-density material at the pith did not have correspondingly high strength. The specific gravity of the wood accruing at a uniform age of 30 years is directly related to the latitude of growth, the heaviest wood being from trees in southern England and the lightest from trees in northern Scotland. (From author's summary.)

254. Bryden, A. W.
1922. Sizes and grades of Pacific coast woods. Timberman, April, pp. 43-45.

255. Buchanan, T. S.
1940. Fungi-causing decay in wind-thrown northwest conifers. J. Forest. 38: 276-281.

256. _____
1948. *Poria weirii*: Its occurrence and behavior on species other than cedars. Northwest Sci. 22(1): 7-12.

The fungus also causes loss to Douglas-fir, western hemlock, and has been found on true firs, Sitka spruce, and ponderosa pine.

257. _____ and Englerth, G. H.
1940. Decay and other volume losses in windthrown timber on the Olympic Peninsula, Washington. U.S. Dep. Agr. Tech. Bull. 733, 29 pp., illus.

Contains detailed tree-volume-loss data for Sitka spruce and other conifer species and discusses loss and salvage. Sitka spruce logs are no longer merchantable 15 years after being windthrown, regardless of size.

258. Buckland, D. C., Molnar, A. C., and Wallis, G. W.
1954. Yellow laminated root rot of Douglas-fir. Can. J. Bot. 32: 69-81.

Describes a variety of *Poria weirii* that attacks several species of conifers, including Sitka spruce, in British Columbia.

259. Bunnell, F. L.
1965. Variations in pollen morphology of selected conifers native to British Columbia. 60 pp. (B.S. in Forestry thesis on file at Univ. Brit. Columbia.)

Describes Sitka spruce pollen grains. There was significant variation in pollen morphology between certain of the sample trees.

260. Burley, J.
1964. Effect of gibberellic acid on seed germination of Sitka spruce. Forest Sci. 10: 206-208.

Concentrations of 0.1, 1.0, and 10 p.p.m. compared with distilled water caused no significant differences in germination rate or capacity. A solution of 100 p.p.m. significantly reduced germinative capacity at 35 days. A table summarizes the conflicting results obtained by 14 authors on the effects of gibberellin on the germination rate and capacity of 15 other conifers.

261. Burley, Jeffery.
1965. Genetic variation in *Picea sitchensis* (Bong.) Carr. 203 pp., illus. Ph.D. thesis, Yale Univ. Ann Arbor: Univ. Microfilms, Inc. (Diss. Abstr. 26(4): 1847.)

262. _____
1965. Genetic variation in *Picea sitchensis* (Bong.) Carr. A literature review. Commonwealth Forest Rev. 44(1): 47-59.

Describes the nature and importance of genetic variation in forest trees, with particular reference to Sitka spruce. The literature referring to patterns and nomenclature of variation is reviewed and it is concluded that the concepts of clinal and ecotypic variation are not mutually exclusive. The natural distribution of Sitka spruce is illustrated and the literature on variation in individual characters is discussed. With the exception of wood qualities, anatomical and morphological traits have received little attention. Most research has been concentrated on variation in total growth and survival as determined from provenance tests. On the basis of its long and continuous range, and from a consideration of the literature, Sitka spruce might be expected to show gradual variation with respect to latitude. However, the number of characters studied and the intensity of sampling have been too low to allow a detailed analysis of the variation pattern. (Author's summary.)

263. _____
1965. Variation in seed characteristics of Sitka spruce. Advancing Frontiers Plant Sci. (New Delhi) 10: 11-24, illus.

Variations in seed characteristics were studied using bulk collections from 30 sources. Seed weight was not significantly related to latitude, but there was a tendency for northerly provenances to have heavier seed. Germination rate was improved by cold soaking, but germinative capacity was not affected by soaking, gibberellic acid, or alternating temperatures. Differences in embryo size and cotyledon numbers are discussed.

264. _____
1965. Karyotype analysis of Sitka spruce, *Picea sitchensis* (Bong.) Carr. Silvae Genet. 14(4): 127-132., illus.

No statistically significant differences were observed in the basic haploid karyotypes of 10 provenances, and the data were pooled to obtain the karyotype of the species. However, there was a significant increase in total haploid complement length and nuclear volume as latitude of seed origin increased. (From author's summary.)

265. _____
1966. Genetic variation in seedling development of Sitka spruce, *Picea sitchensis* (Bong.) Carr. Forestry 39(1): 68-94., illus.

Development of the terminal bud in 1-year seedlings is illustrated and described as a continuous process. The same sequence of morphological events occurred in 47 provenances examined, but timing was different. Flushing was controlled largely by temperature, and the time of flushing reflected temperature regime of the native habitat. The effect of provenance on height growth is discussed.

266. _____
1966. Provenance variation in growth of seedling apices of Sitka spruce. Forest Sci. 12(3): 170-175.

Describes shoot apex development for seedlings of *Picea sitchensis* (Bong.) Carr. from 47 provenances. The three stages previously used to describe this development in other conifers are applicable to this species, but times of initiation and duration of each stage vary among the provenances. Anatomical

evidence confirmed morphological evidence for a pattern of development variation that was closely related to the natural distribution of the species. Elongation and needle production continued into July for seedlings from Alaska and into September for those from California. Bud scale production followed and extended for approximately 1 month. The rest stage extended until April, with only 2 weeks separating the first and last provenances in time of spring flushing. The size and shape of the shoot apex varied during these stages, but the zonation pattern could not be distinguished consistently. (Author's summary.)

267. _____
1966. Variation in colour of Sitka spruce seedlings. Quart. J. Forest. 60(1): 51-54.

Genetic variation was demonstrated among seedlings from 47 provenances of Sitka spruce in the rate of development of stem and needle coloration. The pattern of variation paralleled the natural distribution of the species, reflecting changes in environment through the range. Needle glaucousness was subject to local environmental modification. (Author's summary.)

268. Burns, Findley.
1911. The Olympic National Forest: its resources and their management. U.S. Dep. Agr. Forest Serv. Bull. 89, 20 pp., illus.

269. Buszewicz, G. M.
1967. Forest tree seed. Part I. *In* Report on forest research for the year ended March 1966. Great Brit. Forest. Comm., pp. 16-20. London: H. M. Stationery Office.

270. Buszewicz, G.
1967. Forest tree seed. *In* Report on forest research for the year ended March 1967. Great Brit. Forest. Comm., pp. 22-27. London: H. M. Stationery Office.

The Forest Tree Seed Section is responsible for seed procurement, extraction, processing, storage, testing, and distribution. Similar reports of the Section are available in earlier annual reports of the Forestry Commission.

271. _____ and Holmes, G. D.
1957. Seven years seed testing experience with tetrazolium viability test for conifer species. *In* Report on forest research for the year ended March 1957. Great Brit. Forest. Comm., pp. 142-151. London: H. M. Stationery Office.

Describes the history and technique of the tetrazolium bromide viability test. Results of 766 tests on 11 species, including Sitka spruce, are analyzed and compared with standard Copenhagen tank germinator tests. The tetrazolium results were nearest to the control when seeds having at least five-sixths of the total embryo surface stained were recorded as viable.

272. Buxton, E. W., Sinha, Indu, and Ward, Valerie.
1962. Soil-borne diseases of Sitka spruce seedlings in a forest nursery. Brit. Mycol. Soc. Trans. 45(4): 433-448.

Seedlings at Old Kennington nursery on plots treated annually with formalin for 5 years showed symptoms of damping off, browning of leaves and roots, and stunting. Plants on adjacent plots treated only once with formalin were normal. In an examination of the microflora of the rhizosphere and seedling roots, 13 fungus genera were identified. Microflora may be introduced into the nursery on contaminated seed. Tolerance to formalin may be developed.

273. Cadell, Henry M.
1910. On the growth of the Sitka spruce and other trees in Linlithgowshire and Stirlingshire. Roy. Scot. Arboricult. Soc. Trans. 23: 158-167.

274. Cadman, W. A.
1953. Shelterbelts for Welsh hill farms. Great Brit. Forest. Comm. Forest Rec. 22, 30 pp., illus.

Sitka spruce is a suitable species for shelterbelt planting on wet sites and peaty soils. It grows fast and produces good volumes and will withstand wind as well as other species tested.

275. _____
1955. Farm and forest: 2. Planting of shelterbelts. 3. Layout and choice of species for shelterbelts. Agriculture 62(2): 92-93, illus. 62(3): 142-143.

Discusses shelterbelts in general with special reference to Britain. Sitka spruce is recommended for exposed areas with wet, acid soils. Brief advice on planting and tending is given.

276. Cahalane, Victor H.
1959. A biological survey of Katmai National Monument. Smithsonian Misc. Collect. 138(5), Pub. 4376, 246 pp. plus 17 plates, 1 map.

Small groves or lone specimens of Sitka spruce grow at several locations in Kukak and Kuliak Bays. Trees on Takli Island in Amalik Bay, killed by the ash fall of 1912, were still standing in 1954.

277. Cameron, A. E.
1936. *Adelges cooleyi* Gillette (Hemiptera, Adelgidae) of the Douglas fir in Britain: Completion of its life cycle. Ann. Appl. Biol. 23: 585-605.

Reports on the first discovery in Britain of a viable generation I (sexuales) on Sitka spruce.

278. Campbell, George I.
1952. Some observations on the experience of an amateur with special reference to thinning in an area of rapid growth. Scot. Forest. 6(1): 3-9.

Advises severe early thinning, together with pruning, of Sitka spruce on the west coast of Scotland to take full advantage of the growth potential.

279. Campbell, W. G., and McDonald, I. R. C.
1952. The chemistry of the wood cell wall. Part I. The delignification of beech and spruce woods by sodium chlorite in buffered aqueous solution. J. Chem. Soc. 1952: 2644-2650.

Some 90 percent of acid lignin can be removed without significant loss of polysaccharide, but attempts to delignify the wood residues further cause appreciable loss.

280. Canada Forest Service.
1926. Sitka spruce. Can. Forest Serv. Tree Pam. 12, 6 pp., illus.

281. Canada Department of Forestry.
1951. Canadian woods: their properties and uses. Ed. 2, 367 pp., illus. Ottawa: Queen's Printer.

282. _____
1963. Native trees of Canada. Ed. 6, Can. Dep. Forest. Bull. 61, 291 pp., illus.

283. Capps, Stephen R.
1937. Kodiak and vicinity, Alaska. U.S. Dep. Int. Geol. Surv. Bull. 868-B, pp. 93-134, illus.

284. Carl, G. Clifford, Guiguet, C. J., and Hardy, George A.
1952. A natural history survey of the Manning Park area, British Columbia. Brit. Columbia Prov. Mus. Occas. Pap. 9, 130 pp., illus.

285. Carlisle, A., and White, E. J.
1962. Establishment of trees on Pennine moorland: species trials at Moor House. Great Brit. Natur. Conserv. Rep. 1961/62: 60-61.

Describes problems encountered in establishing trees. A few (200) Sitka spruce, including 100 of Alaskan provenance, were planted in the Nether Hearth enclosure.

286. Carmichael, Ralph L., and Dick, James.
1956. A seeding of Sitka spruce-western hemlock in southwestern Washington. Northwest Sci. 30(2): 56-60.

Describes experimental helicopter seeding of Sitka spruce and western hemlock on three accidental burns in southwestern Washington. The seeding was successful on each of the burns. Broadcast seeding of Sitka spruce and western hemlock is recommended as an effective method of artificial reforestation for recent burns in the Sitka spruce-western hemlock type of southwestern Washington.

287. Carrasco, Mario M.
1954. Primeros resultados de reforestacion con coniferas exoticas en las zonas Pre-Cordilleranas de la Provincia de Valdivia. [Preliminary results of afforestation with exotic conifers in the Andean foothills of Valdivia Province.] Bosques y Maderas (special issue of Chile Maderero) 1954: 12-14. [In Spanish.]

An attempt to establish Sitka spruce proved unsuccessful.

288. Carriere, Elie-Abel.
1855. Traite general des Coniferes. [General dissertation on the conifers with descriptions of all species and varieties.] 656 pp. Paris: Chez L'Auteur. [In French.]

289. Carstensen, John P.
1961. Gluing characteristics of softwood veneers and secondary western hardwoods. Forest Prod. J. 11: 313-315.

290. Cartwright, K. St. G.
1930. A decay of Sitka spruce timber, caused by *Trametes serialis*, Fr. A cultural study of the fungus. Great Brit. Dep. Sci. & Ind. Res. Forest Prod. Res. Bull. 4, 26 pp. plus 6 plates.

291. _____ and Findlay, W. P. K.
1931. The effect of progressive decay by *Trametes serialis*, Fr. on the mechanical strength of the wood of Sitka spruce. Great Brit. Dep. Sci. & Ind. Res. Forest Prod. Res. Bull. 11, 18 pp. plus 9 figs.

292. Cary, N. LeRoy.
1922. Sitka spruce: its uses, growth, and management. U.S. Dep. Agr. Bull. 1060, 38 pp., illus.

A comprehensive discussion of the silvics, management, production, and uses of Sitka spruce.

293. _____
1922. Sitka spruce: its uses, growth, and management. Timberman 23(9): 140-144.

294. Cash, Edith K.
1958. Some new Discomycetes from California. Mycologia 50: 642-656, illus.

295. Cech, M., Kralik, O., and Blattny, C.
1961. Rod-shaped particles associated with virosis of spruce. Phytopathology 51(3): 183-185.

Rod-shaped particles have been found in exudates from twigs of Sitka spruce. Infected trees have shortened chloratic needles, and defoliation is frequently severe. The virus is probably identical with that described from Norway spruce in Czechoslovakia where it is transmitted by *Adelges abietis*.

296. Cecil, George H.
1913. Alaska lumber industry gives evidence of attaining considerable size. Timberman 14(11): 46.

297. _____
1920. Alaska pulpwood resources to be developed. Timberman 21(8): 36-38.

298. Chalk, L.
1930. Tracheid length with special reference to Sitka spruce. Forestry 4: 7-14.

299. _____ and Bigg, J. M.
1956. The distribution of moisture in the living stem in Sitka spruce and Douglas-fir. Forestry 29(1): 5-21.

Summer moisture content in Sitka spruce was highest on the site with the highest rainfall and lowest on the site with the lowest rainfall. Moisture content decreased suddenly in late summer. There was a sharp moisture gradient from cambium to heartwood, the saturated zone being very narrow except on the wet Sitka spruce site.

300. Chard, J. S. R.
1964. The Roe deer. Great Brit. Forest. Comm. Leafl. 45, 26 pp., illus.

In a 12-year-old plantation, Sitka spruce showed no significant browse damage, because of its prickly foliage. In contrast, Norway spruce was severely hedged.

301. Charles, W. N.
1956. The effects of a vole plague in the Carron Valley, Stirlingshire. Scot. Forest. 10(4): 201-204.

Describes effects of voles on ground vegetation and attack in young trees. *Picea abies*, *P. sitchensis*, and *Pinus sylvestris* were heavily attacked; *P. sitchensis* alone resprouted from below the damaged area.

302. Charlon, J. C.
1958. Die Düngewirkung von Thomasphosphat bei Waldbäumen. [The fertilizing effect of basic slag on forest trees.] Phosphorsäur 18: 220-224. [In German.]

303. _____
1961. Essais de fertilisation sur arbes forestiers. [Fertilizer trials on forest trees.] C. R. Acad. Agr. (France) 47(6): 288-292. [In French.]

Presents summarized results of fertilizer trials with basic slag on Sitka spruce and other conifers on various sites in western France, 1954-60. Basic slag (400 grams per plant) and nitrate fertilizer (100 grams and 200 grams per plant) were used. Marked increases in early growth were noted in comparison with untreated controls.

304. Chaytor, A. H.
1920. Planting Douglas-fir and Sitka spruce in cleared coppice. Quart. J. Forest. 14: 161-164.

305. Chen, Hsien-Fang.
1955. Growth and mineral uptake of Sitka spruce (*Picea sitchensis*) in solution cultures. 69 pp., illus. (M.S. thesis on file at Univ. Wash.)

Sitka spruce seedlings grown in mineral solutions in the greenhouse were weak and stunted in both low N and low P treatments; serious necrosis and reduced growth were seen in the low Mg solution; development was somewhat retarded in low K, low Ca, and minus B treatments; and no major effect was noted between low S and minus Fe treatments and the control. Nutrient levels found in deficient foliage are given.

306. Chen, Peter Yuen San, and Bossfeld, Ralph.
1964. Effect of viscosity on permeability of Sitka spruce to aqueous glycerin. Tappi 47: 750-752.

307. Childs, T. W., and Clark, J. W.
1953. Decay of windthrown timber in western Washington. U.S. Bur. Plant Ind. Forest Pathol. Spec. Release 40, 20 pp.

Measurements in windthrown Douglas-fir, Sitka spruce, western hemlock, and Pacific silver fir indicate that hemlock and silver fir decay rapidly in all local conditions in this region, that Sitka spruce decays fairly rapidly, and that Douglas-fir heartwood is quite durable though its sapwood decays fairly rapidly. Temperature is probably the principal factor, other than diameter, determining the rate of decay in fallen trees. In all species, decay is usually negligible in the first year after windthrow but is well started in the sapwood by the end of the second year.

308. Chopinet, R.
1962. Les Tsuga et leurs hybrides. III. Especes d'origine hybride. [The hemlocks and their hybrids. III. Species of hybrid origin.] Rev. Hort. 134(2.247): 266-268. [In French.]

Describes two purported intergeneric crosses between *Picea sitchensis* and *Tsuga heterophylla*.

309. Christie, J. M.
1958. Alignment charts and form height tables for determining stand volumes of conifers, oak, and beech. Great Brit. Forest. Comm. Forest. Rec. 37, 18 pp.

Includes tables of form height, and alignment charts, for Scots pine, Corsican pine, European larch, Japanese larch, Norway spruce, Sitka spruce, Douglas-fir, western hemlock, grand fir, oak, and beech.

310. Chrystal, R. N.
1916. The forest-insect problem in Stanley Park. Brit. Columbia Entomol. Soc. Proc. 9: 63-64.

Describes effects of *Chermes cooleyi*, *Aphis abietina*, and *Dendroctonus obesus* on Sitka spruce in Stanley Park at Vancouver, British Columbia.

311. Clapham, A. R., Tutin, T. G., and Warburg, E. F.
1952. Flora of the British Isles. 1591 pp. Cambridge: Cambridge Univ. Press.

312. Clapp, Earle H., and Boyce, Charles W.
1924. How the United States can meet its present and future pulpwood requirements. U.S. Dep. Agr. Bull. 1241, 100 pp., illus.

Includes a description of the role of Sitka spruce.

313. Clark, Brian John.
1965. Variation in cone and seed characteristics of Sitka spruce in British Columbia. 78 pp., illus. (B.S. in Forestry thesis, on file at Univ. Brit. Columbia.)

314. Clifford, N.
1957. Timber identification for the builder and architect. 141 pp., illus. London: Leonard Hill, Ltd.

Describes briefly the color, characteristics, durability, and suitable uses of Sitka spruce wood.

315. Cole, Bert L., and Webster, L. T.
1962. Timber harvest report. Wash. Dep. Natur. Resources, 40 pp.

316. Coleman, Babette Brown, Muencher, Walter C., and Charles, Donald R.
1956. A distributional study of the epiphytic plants of the Olympic Peninsula, Washington. Amer. Midland Natur. 56(1): 54-87.

Sitka spruce was second only to red alder in relative receptivity to epiphytes. Epiphytes found on Sitka spruce are listed.

317. Colhoun, J., McElroy, G., and Ward, P. J.
1961. Wastage of apples in relation to the wood used for storage boxes. Plant Pathol. 10(3): 116-118.

Apples stored in boxes made of Sitka spruce showed no damage.

318. Colley, Reginald H.
1921. The effect of incipient decay on the mechanical properties of airplane timber. Phytopathology 11: 45.

319. Collingwood, G. H., and Brush, Warren D.
1964. Knowing your trees. (Rev. and ed. by Devereux Butcher.) 349 pp., illus. Wash., D. C.: Amer. Forest. Ass.

320. Colquhoun, M. K.
1951. The wood pigeon in Britain. Great Brit. Agr. Res. Counc. Rep. 10, 69 pp.

Wood pigeons sometimes damage young conifers by perching on the leading shoot, which results in its being bent at right angles or broken, so that the tree forks and the general shape is spoiled. Sitka spruce suffers most.

321. Condrashoff, S. F.
1964. Sitka spruce terminal damage. Can. Dep. Forest. Forest Entomol. Pathol. Br. Annu. Rep. 1964: 132-133.

Damage to terminal buds of Sitka spruce on the Queen Charlotte Islands is caused primarily by *Epinotia* n. sp. *Zeiraphera* nr. *ratzeburgiana* and a gall midge, *Rhabdophaga* sp. nr. *Swainei*. An eriophyid mite, *Trisetacus grosmanni* (Keifer), is involved mainly in damage to lateral buds. Life histories of these insects are mentioned briefly.

322. ———
1966. Larval descriptions of *Zeiraphera pacifica* Freeman and *Epinotia hopkinsana* (Kearfott) (Lepidoptera: Olethreutidae). Can. Entomol. 98: 703-706, illus.

Full-grown larvae of *Zeiraphera pacifica* Freeman and *Epinotia hopkinsana* (Kearfott) are described and illustrated. Both insects have attracted attention in recent years by their damage to stands of young Sitka spruce on the Queen Charlotte Islands. The larvae destroy the terminal buds, altering form and height growth of the trees. The potential economic significance of these pests has necessitated annual population surveys and biological studies, the effectiveness of which depends in part on identification of the larvae. (From author's summary.)

323. Conn, H.
1958. Stem analysis of trees at Baronscourt. Forest. Northern Ireland 1(4): 25-30.

324. Cooke, Wm. Bridge.
1955. Some fungi from Alaska. Northwest Sci. 29(4): 127-138.

Lists the following fungi occurring on living or dead Sitka spruce as species new to Alaska: *Hypoxylon coccineum, Corticium hiemalis, Corticium microsporum, Peniophora glebulosa,* and *Phlebiella vaga.* Other species not new to Alaska are also reported.

325. _____ and Lawrence, Donald B.
1959. Soil mould fungi isolated from recently glaciated soils in southeastern Alaska. J. Ecol. 47: 529-549, illus.

326. Cooper, W. S.
1923. The recent ecological history of Glacier Bay, Alaska. II. The present vegetation cycle. Ecology 4(3): 223-246, illus.

327. Cooper, William S.
1930. The seed plants and ferns of the Glacier Bay National Monument, Alaska. Torrey Bot. Club Bull. 57: 327-338.

328. _____
1931. A third expedition to Glacier Bay, Alaska. Ecology 12(1): 61-95, illus.

329. _____
1931. The layering habit in Sitka spruce and the two western hemlocks. Bot. Gaz. 91: 441-451, illus.

Western hemlock and mountain hemlock were found to layer, although not so commonly or vigorously as Sitka spruce.

330. _____
1937. The problem of Glacier Bay, Alaska: a study of glacier variations. Geogr. Rev. 27(1): 37-62, illus., plus map.

331. _____
1939. Additions to the flora of the Glacier Bay National Monument, 1935/36. Torrey Bot. Club Bull. 66: 435-436.

332. _____
1939. A fourth expedition to Glacier Bay, Alaska. Ecology 20(2): 130-155, illus.

333. _____
1942. Vegetation of the Prince William Sound region, Alaska; with a brief excursion into post-Pleistocene climatic history. Ecol. Monogr. 12: 1-22, illus.

334. _____
1957. Vegetation of the Northwest-American Province. Pacific Sci. Congr. Proc. 8(4): 133-138.

Sitka spruce is listed as one of the 12 character trees of the province.

335. Cooper, William Skinner.
1923. The recent ecological history of Glacier Bay, Alaska. I. The interglacial forest of Glacier Bay. Ecology 4(2): 93-128, illus., plus map.

336. _____
1924. The forests of Glacier Bay--present, past, and yet unborn. J. Forest. 22: 16-23, illus.

337. Corliss, J. F., and Dyrness, C. T.
1965. A detailed soil-vegetation survey of the Alsea area in the Oregon Coast Range. *In* Forest-soils relationships in North America, Chester T. Youngberg (ed.). Second North Amer. Forest Soils Conf. Proc. 1963: 457-483, illus.

338. Cornwall, Geo. M.
1926. Christening Pacific coast woods. Timberman 28(1): 87, 90, 92.

339. Cote, W. A., Jr.
1965. Cellular ultrastructure of woody plants. Advanced Sci. Seminar Proc. 1964. 603 pp., illus. Syracuse, New York: Syracuse Univ. Press.

340. Coville, Frederick Vernon, and Funston, Frederick.
1895. Botany of Yakutat Bay, Alaska, with a field report. U.S. Nat. Herb. Contr. 3(6): 325-353.

341. Cowan, Ian McTaggart.
1945. The ecological relationships of the food of the Columbian black-tailed deer, *Odocoileus hemionus columbianus* (Richardson), in the coast forest region of southern Vancouver Island, British Columbia. Ecol. Monogr. 15(2): 109-139.

Sitka spruce is listed as slightly palatable. New growth is eaten early in spring, casually or under stress.

342. Cowan, William C.
1962. Shear stress in two wood beams over wood block supports. USDA Forest Prod. Lab. Rep. 2249, 52 pp., illus.

Presents and analyzes the results of two experiments to determine the horizontal shear-stress distribution in wood beams (straight-grained, clear Sitka spruce specimens) over points of support.

343. Cowdrey, D. R., and Preston, R. D.
1966. Elasticity and microfibrillar angle in the wood of Sitka spruce. Roy. Soc. Proc. (London) 166B(1004): 245-272.

344. Cowling, Ellis B.
1962. Influence of transient capillaries on the enzymatic degradation of plant cell walls. Phytopathology 52(1): 6.

345. _____ and Sachs, Irving B.
1960. Detection of brown rot with osmium tetroxide stain. Forest Prod. J. 10: 594-596.

A 1-percent (weight per volume) aqueous solution of OsO_4 produced a dark stain in less than 5 minutes on specimens of southern pine, Sitka spruce, and sweetgum infected with brown-rot fungi, but took more than 20 minutes to stain sound wood or wood infected with white rot.

346. Cox, William T.
1911. Reforestation on the National Forests. Part I.--Collection of seed. Part II.--Direct seeding. U.S. Dep. Agr. Forest Serv. Bull. 98, 57 pp., illus.

347. Crampton, C. B.
1966. Soils, forests, and pastures in South Wales. Forestry 39(2): 171-188.

348. Crocker, Robert L., and Dickson, B. A.
1957. Soil development of the recessional moraines of the Herbert and Mendenhall Glaciers, south-eastern Alaska. J. Ecol. 45: 169-185, illus.

349. _____ and Major, Jack.
1955. Soil development in relation to vegetation and surface age at Glacier Bay, Alaska. J. Ecol. 43(2): 427-448.

Describes the main steps in vegetation development from initial colonization of the bare surfaces to establishment of a forest dominated by Sitka spruce.

350. Crooke, Myles.
1960. *Adelges cooleyi*, an insect pest of Douglas-fir and Sitka spruce. Great Brit. Forest Comm. Leafl. 2, 8 pp., illus.

351. _____
1962. The United Kingdom's position in relation to the changed status of the giant spruce bark beetle, *Dendroctonus micans* Kug., in Europe. Eighth Brit. Commonwealth Forest. Conf., East Africa, 1962. Great Brit. Forest. Comm. 7 pp.

Indicates the danger to British forestry of the possible importation of *D. micans*, which, on the continent of Europe, severely damages Sitka spruce stands. The import restriction order designed to reduce the risk is described. (From author's summary.)

352. Crosby, David.
1965. Conditions of forest insects in forest regions, Alaska. *In* Forest insect conditons in the United States, 1964, p. 37. Forest Serv. U.S. Dep. Agr.

353. _____
1966. Conditions of forest insects in forest regions, Alaska. *In* Forest insect conditions in the United States, 1965, p. 43. Forest Serv. U.S. Dep. Agr.

354. _____
1967. Forest conditions in the various regions, Alaska. *In* Forest insect conditions in the United States, 1966, pp. 7-9, illus. Forest Serv. U.S. Dep. Agr.

355. _____ and Baker, Bruce H.
1966. Forest insect and disease conditions in Alaska during 1966. USDA Forest Serv., Alaska Reg. 10, Div. Timber Manage., 11 pp., illus.

356. Crowther, E. M.
1950. Committee on nutrition problems in forest nurseries: summary report on 1948 experiments. *In* Report on forest research for the year ended March 1949. Great Brit. Forest. Comm., pp. 60-64. London: H. M. Stationery Office.

Transplant manuring experiments with Sitka spruce in a very acid moorland soil and on a calcareous agricultural soil showed large responses in height to superphosphate applied before lining out and to ammonium sulphate given as a top dressing in April. The only failure was on an unusually acid sandy soil (pH 4.0) where a top dressing with ammonium sulphate checked height growth. Other soluble N fertilizers gave good results.

357. _____
1951. Nutrition problems in forest nurseries. *In* Report for 1950, pp. 40-41. Rothamsted [England] Exp. Sta.

Sitka spruce seedlings showed large responses to each of the major nutrients on very acid soils. In neutral or slightly acid soils of old nurseries, Sitka spruce generally made poor growth even when well manured with compost or fertilizers.

358. _____
1951. Sub-committee on nutrition problems in forest nurseries: summary report on 1949 experiments. *In* Report on forest research for the year ended March 1950. Great Brit. Forest. Comm., pp. 97-105. London: H. M. Stationery Office.

A positive response of Sitka spruce to phosphate was observed. Nitrogen depressed growth during a drought year.

359. _____, Warren, R. G., and Benzian, B.
1951. Nutrition problems in forest nurseries. Rothamsted [England] Exp. Sta. Rep. 1950: 40-41.

Sitka spruce seedlings showed large responses to each of the major nutrients in experiments on very acid soils, but in some of these experiments composts well supplied with N, P, and K gave better results than inorganic fertilizers. It appeared that fertilizer N applied in the seedbeds in spring and in an early summer top-dressing had been leached out of the surface soil during the very wet summer and autumn before the period of most active growth. In the neutral or slightly acid soils of old nurseries, Sitka spruce seedlings generally make very poor growth, even when well manured with compost or fertilizers. In 1950, at several nurseries, there were striking responses on such soils to acidification in previous years by $(NH_4)_2SO_4$ or S. Repeated dressings of $(NH_4)_2SO_4$ appear to provide a safe method of supplying available N and at the same time acidifying the soil. Soil sterilization to prevent damping off is also discussed.

360. Crozier, John D.
1910. The Sitka spruce as a tree for hill planting and general afforestation. Roy. Scot. Arboricult. Soc. Trans. 23: 7-16 plus 1 plate.

361. Cunliffe, N.
1921. Defoliation of spruce by aphis (*Myzaphis abietina* Walker). Quart. J. Forest. 15: 213-214.

362. _____ and Ryle, G. B.
1923. The conifer spinning mite on Sitka spruce. [*Oligonychus* (*Paratetrauchus*) *ununguis*, Jacobi.] Quart. J. Forest. 17: 359-362.

363. Currier, Raymond A.
1963. Compressibility and bond quality of western softwood veneers. Forest Prod. J. 13: 71-80.

364. Curry, W. T.
1952. The effect of moisture content on the tensile strength of Sitka spruce. Aircraft Eng. 24(279): 142-143.

Test showed that on the average, a change in moisture content within the range 9 to 20 percent had no significant effect on tensile strength, but an increase to saturation significantly reduced it. The tensile strength for wood below 20-percent moisture content averaged 18,730 pounds per square inch, and at saturation, 14,750 pounds per square inch. The effect of moisture on strength varied with density.

365. _____
1961. Working stresses for structural laminated timber. Great Brit. Forest Prod. Res. Board Spec. Rep. 15, 50 pp., illus.

Reports and tabulates basic stresses for laminated timber of imported woods, including Sitka spruce, for dry and damp exposures.

366. Curtis, Carlton C., and Bausor, S. C.
1943. The complete guide to North American trees. 337 pp., illus. New York: New Home Library.

367. Dachnowski-Stokes, A. P.
1941. Peat resources in Alaska. USDA Bur. Plant Ind. Div. Soil Surv. Tech. Bull. 769, 84 pp., illus.

368. Dallas, W. G.
1962. The progress of peat afforestation in northern Ireland. Irish Forest. 19(1): 84-93.

Since 1955, Sitka spruce has been the principal species used for peatland afforestation in northern Ireland.

369. Dallimore, W.
1907. Visit to Newport and South Wales. Kew Bull., pp. 388-396.

Details of 70-year-old specimen trees 90 to 100 feet tall at Singleton Abbey are noted on page 393.

370. _____
1912. Notes on Durris Estate. Kew Bull., pp. 325-326.

371. _____
1912. VI.--Notes on trees suitable for experimental forestry. III. American conifers. Roy. Bot Gard., Kew, Misc. Inform. Bull. 2: 75-85.

372. _____
1948. A very fine specimen of Sitka spruce (*Picea sitchensis*). Quart. J. Forest. 42: 162-163.

373. _____
1955. The National Pinetum. *In* Guide to National Pinetum and forest plots at Bedgebury. Ed. 2. Great Brit. Forest. Comm., pp. 6-22.

374. _____ and Jackson, A. Bruce.
1923. A handbook of Coniferae including Ginkgoaceae. Ed. 1, 570 pp., illus. New York: Longmans, Green & Co., London: Edward Arnold & Co. (Ed. 4, 1966, rev. by S. G. Harrison, 729 pp., illus.)

375. Darker, G. D.
1932. The Hypodermataceae of conifers. Arnold Arboretum Contrib. 1, 131 pp.

376. Darlington, C. D., and Wylie, A. P.
1955. Chromosome atlas of flowering plants. Ed. 2, 519 pp., illus. London: George Allen & Unwin, Ltd.

Sitka spruce chromosome number is 24.

377. Daubenmire, Rexford F.
1953. Notes on vegetation of forested regions of the far northern Rockies and Alaska. Northwest Sci. 27(4): 125-138.

378. Davidson, Eric Duncan.
1967. Synecological features of a natural headland prairie on the Oregon coast. 79 pp., illus. (M.S. thesis on file at Oreg. State Univ., Corvallis.)

Describes ecotone between natural prairie and Sitka spruce-western hemlock forest.

379. Davidson, J. C. N.
1959. Silvical characteristics. *In* Forest handbook for British Columbia. Ed. 2, pp. 557-571. Vancouver: Forest Club, Univ. Brit. Columbia.

Describes silvical characteristics of Sitka spruce, including information on soil requirements.

380. Davidson, John, and Abercrombie, I.
1927. Conifers, junipers, and yew: gymnosperms of British Columbia. 72 pp., illus. London: T. Fisher Unwin.

381. Davidson, Ross W., and Lombard, Frances.
1954. Brick red stain of Sitka spruce and other wood substrata. Phytopathology 44: 606-607.

382. Davies, E. J. M.
1966. Dappled shade work with Sitka spruce. Scot. Forest. 20(1): 52-55.

Describes planting Sitka spruce beneath scrub birch. By careful planting, a conifer crop can be established cheaply and safely without heavy clearing.

383. _____
1967. Aerial fertilization at Kilmory Forest. Scot. Forest. 21(2): 99-104, illus.

Applications of ground mineral phosphate on small plots of slow-growing Sitka spruce in the West Scotland Conservancy resulted in a tripling of leader growth and led to recent large-scale applications at Kilmory Forest. Regular aerial applications of fertilizer are foreseen as a standard silvicultural practice. Fertilization can also extend the range of highly productive species such as Sitka spruce to infertile sites currently managed for lodgepole pine.

384. _____
1967. Silviculture of the spruces in West Scotland. Forestry 40(1): 37-46.

An account of the silviculture of Norway and Sitka spruce practiced in the West (Scotland) Conservancy of the Forestry Commission in the past 50 years. Present methods are summarized and future developments forecast. A more intensive form of silviculture is advocated for Sitka spruce. (Author's summary.)

385. Day, R. J.
1967. A plea for standard tree name abbreviations. Forest. Chron. 43: 121-134.

The author proposes a system for abbreviating tree names in the vernacular. Simple rules are set forth and a list of abbreviations presented. The following is proposed for *Picea sitchensis:* abbreviation--PI's, English vernacular--Sitka spruce, French vernacular--Epinette de Sitka.

386. Day, W. R.
1928. Damage by late frost on Douglas-fir, Sitka spruce, and other conifers. Forestry 2: 19-30.

387. _____
1947. On the effect of changes in elevation, aspect, slope, and depth of freerooting material on the growth of European larch, Japanese larch, Sitka spruce, and Scots pine in Mynydd Duu Forest. Forestry 20: 7-20, illus.

388. _____
1949. The soil conditions which determine wind-throw in forests. Forestry 23: 90-95.

The effect of soil conditions on root development and anchorage against windthrow in Britain is examined briefly. Particular soil and vegetation types are mentioned, with special reference to spruce.

389. _____
1950. Root disease and butt-rot of conifers. Imp. Forest. Inst. Rep. (Oxford) 1948/49: 11-12.

390. _____
1950. The drought-crack of conifers. Imp. Forest. Inst. Rep. (Oxford) 1948/49: 12-13.

Cracking occurred over a wide area in Wales and parts of Scotland. An examination of the anatomy of the affected trees showed that drought was the probable cause. Sitka and Norway spruces have been the most seriously affected by drought-crack, but all the conifers commonly grown, except the pines, have been affected. The same phenomenon has also been reported from Denmark.

391. _____
1950. The fungus flora of spruce stems. Imp. Forest. Inst. Rep. (Oxford) 1948/49: 14.

Borings taken in the main stems of living and outwardly uninjured Sitka spruce showed that they were colonized by various species of fungi. Borings taken in Sitka spruce of the same size elsewhere did not show any fungus flora. This colonization seems to have been made possible by debility caused by disease. The discovery that spruce may bear a fungus flora in their wood, even when they appear to be healthy as judged by the appearance of the crown, is a matter of considerable importance in view of the extensive use of spruces in afforestation in Great Britain.

392. _____
1950. Forest hygiene. II. The imperfection of the environment and its importance in the management of forests. Empire Forest. Rev. 29(4): 307-315.

Discusses the environmental factors in the development of disease, illustrated by data on the influence of soil profiles on the growth of Sitka spruce.

393. _____
1951. Root disease of conifers with special reference to the dying of Sitka spruce and its liability to wind-throw. Imp. Forest. Inst. Rep. (Oxford) 1949/50: 12-13.

394. _____ 1951. The fungus flora of live spruce stems. Imp. Forest. Inst. Rep. (Oxford) 1949/50: 13-14.

Isolation made from drought-cracked trees shows that their wood is always colonized by fungi, some of which are hymenomycetes known to cause decay of timber. Most have proved to be either ascomycetes or *fungi imperfecti*. Heartwood of trees that had not suffered from drought-crack or other known injury, but which grew among drought-cracked trees, also contained fungi, though to a lesser extent.

395. _____ 1952. Root disease of conifers in relation to soil conditions. (a). Development of butt-rot in conifers in relation to soil depth. (b). The dying of Sitka spruce. Imp. Forest. Inst. Rep. (Oxford) 1950/51: 13-14.

396. _____ 1953. The fungus flora of the main stem of standing trees. Imp. Forest. Inst. Rep. (Oxford) 1951/52: 15.

Samples of Sitka spruce from Aberdeenshire that had suffered from drought-crack in 1947 showed general infection of the heartwood by *Fomes annosus*. In order to determine whether *F. annosus* was present over any wider area, standing trees were sampled in Pitfichie Forest. Both cracked and uncracked trees were sampled, and all the cracked and most of the uncracked trees had heartwood infected with mycelia. These have not been identified, but *F. annosus* was not present and it is unlikely that most of the mycelia are active in wood destruction.

397. _____ 1953. The growth of Sitka spruce on shallow soils in relation to root disease and wind-throw. Forestry 26(2): 81-95.

398. _____ 1954. Cambial injuries on the main stem of conifers. Imp. Forest. Inst. Rep. (Oxford) 1952/53: 13-14.

399. _____ 1954. Drought crack of conifers. Great Brit. Forest Res. Forest. Comm. Rep. 26, 40 pp., illus.

Norway and Sitka spruce were affected by drought-crack following the exceptional drought of 1947. Drought-crack was shown to be correlated with shallow rooting depth in otherwise good soils. A secondary cause of the injury may be the light, poor structure of the wood and the occurrence of heart rot. A number of fungi associated with the condition are listed.

400. _____ 1955. The place of a species in the forest, with special reference to western North American species of conifer used in Britain. Forestry 28(1): 33-47.

Differences between climates of Queen Charlotte Islands and of England and Wales are discussed briefly. The site tolerance of the principal species

within their own natural range is examined, with particular reference to Sitka spruce. Observing the climatic and edaphic position of species in their natural range suggests their place in Britain.

401. _____ 1957. Sitka spruce in British Columbia: a study in forest relationships. Great Brit. Forest. Comm. Bull. 28, 110 pp. plus 57 plates.

Results of a study, based on fieldwork in two regions of the coastal forest in British Columbia (Graham Island, and Terrace in the Skeena River drainage). Discusses the relationship between soil conditions and growth of Sitka spruce, specifically with respect to rooting depth, root and crown development, vigor, and stand conditions.

402. _____ 1958. Forest pathology: studies in 30- to 35-year-old, even-aged spruce stands with reference to the development of fluting, bark necrosis, and variations in crown density. Imp. Forest. Inst. Rep. (Oxford) 1957/58: 13-15.

403. _____ 1959. The influence of pathogenic factors in the rooting space on the development of even-aged plantations. Advance. Sci. 16(63): 212-236. (Also in 1960 Quart. J. Forest. 54(1): 33-53 and 1960 Empire Forest. Rev. 39(1): 38-53.)

Discusses, with some examples from Norway and Sitka spruce in Britain, the variations in survival and growth rate that occur with varying site-water relationships and soil types and depths. Gives illustrations from Britain, Denmark, Holland, and Germany of soil conditions in which disease (root infection with or without insect attack) of Sitka spruce has occurred as a result of deficiencies in the rooting space.

404. _____ 1960. Bark necrosis of Sitka spruce, Douglas-fir, and Norway spruce. Imp. Forest. Inst. Rep. (Oxford) 1959/60: 15-16.

405. _____ 1962. Notes on the development of the root system with Sitka spruce. Scot. Forest. 16(2): 72-83, illus.

A short discussion, based mainly on field observation, of the factors that appear to be important in the development of long, ropelike roots on Sitka spruce. It is suggested that the physical character of the soil is usually of basic importance, but that chemical and biotic factors often also play a part. (From author's summary.)

406. _____ 1963. The development of Sitka spruce on shallow peat. Scot. Forest. 17(4): 219-236.

407. _____ 1964. The development of flutes or hollows on main stems of trees and its relation to bark splitting and strip necrosis. Forestry 37(2): 145-160.

Field observations of Sitka spruce in Britain showed that flutes and strip necrosis often develop above the junction of two main roots or above a dead root, whereas ridges commonly are associated with actively functioning roots. Flutes, strip necrosis, and stem splitting are attributed to a submarginal supply of water that becomes most critical in the affected areas.

408. _____
1966. Biological aspects of thinning in conifer plantations. Forestry 39(2): 191-212.

Discusses thinning generally, with particular regard to effects of soil variability. Data on Sitka spruce plantations are used as examples.

409. _____ and Peace, J. R.
1946. Spring frosts. Ed. 2. Great Brit. Forest. Comm. Bull. 18, 111 pp., illus.

Sitka spruce was the species of economic importance most extensively damaged by the severe frosts of late April 1945 in Great Britain.

410. Dayton, William A.
1952. United States tree books; a bibliography of tree identification. U.S. Dep. Agr. Bibliogr. Bull. 20, 32 pp.

411. DeBrit, G.
1967. Disease of older stages. Dep. Lands, Ireland, Forest. Div. Forest Res. Rev. 1957/64: 37-40.

Examination of 36 trees marked for cutting in a 56-year-old Sitka spruce plantation revealed 18 trees infected with *Fomes annosus*. Volume loss in infected trees averaged 13.6 percent.

412. Decker, Henry F.
1966. Plants. *In* Soil development and ecological succession in a deglaciated area of Muir Inlet, southeast Alaska. Inst. Polar Studies Rep. 20, Part 4, pp. 73-96, illus.

Discusses the successional status of Sitka spruce and other plants on recently deglaciated land.

413. Decourt, N.
1964. Remarques sur la relation entre les circonférences à hauteur d'homme et les circonférences à hauteur de souche dans les peuplements forestiers. [The relation between g.b.h. and butt girth in forest stands.] Rev. Forest. Franc. 16(3): 216-224. [In French.]

Gives equations for obtaining girth at breast height from butt girth for several conifer species including Sitka spruce.

414. Defenbaugh, James E.
1906. History of the lumber industry of America. Vol. 1, 559 pp. Chicago: The American Lumberman.

415. Deffenbacher, Forrest W., and Wright, Ernest.
1954. Refrigerated storage of conifer seedlings in the Pacific Northwest. J. Forest. 52: 936-938.

Nursery and field comparisons of freshly dug plants showed that survival in Douglas-fir, noble fir, ponderosa pine, and Sitka spruce is not impaired by storage up to 6 months if humidity is held at 90-95 percent and temperature at 33° to 35°F., and if the air is adequately circulated. The roots should be packed in moist, washed shingle-tow (from western redcedar) or in moss, and wrapped in waterproof bundles with tops exposed. Mycorrhizae are apparently unaffected.

416. Delevoy, M. G.
1907. Naturalisation des essences exotiques. L'Epicea de Sitka. Ann. Gembloux 17(7): 378-400, illus. [In French.]

417. Department of Lands and Forests, British Columbia.
1957. Continuous forest inventory of British Columbia. Victoria. Brit. Columbia Forest Serv., 223 pp., illus., plus map and tables.

Gives a comprehensive inventory of the forests of British Columbia including the coastal Sitka spruce zone.

418. DeSilva, J. A. M.
1961. Moisture relations of Sitka spruce (*Picea sitchensis* Carr.) seedlings under conditions of varying soil moisture supply. J. Oxford Univ. Forest. Soc. 5(9): 21-26, illus.

Experiments on 1-year seedlings of Sitka spruce, sampled direct from the seedbed and grown in containers in which the soil was allowed to dry out, have shown that as the soil moisture fell below field capacity the water deficit in the needles increased and transpiration decreased. (From author's summary.)

419. Dick, James.
1954. The effect of tetramine rodent repellent coating of certain lots of Sitka spruce and western hemlock seed. Weyerhaeuser Forest. Res. Note 24, 2 pp., illus.

420. Dickson, D. A.
1966. The effect of nitrogenous and phosphatic fertilisers on the growth of checked trees on deep peat. Northern Ireland. Min. Agr. Res. Rec. 1965, 14(2): 61-71, illus.

Presents results of an investigation into the mineral nutrition of Sitka spruce and Contorta pine planted 24 years before, on deep ombrogenous peat. Analysis was made of nutrient content in foliage and in peat. It is concluded that, under the conditions investigated, the single application of large quantities of soluble mineral fertilizers to checked plantations is not an efficient practice.

421. _____
1966. The effect of nitrogenous and phosphatic fertilisers on the growth of checked trees on deep peat. Forest. N. Ireland 7(3): 18-32, illus.

422. Dickson, J. A., and Innes, R. A.
1959. Forestry in North Scotland. Forestry 32(1): 65-109.

Discusses forestry in North Scotland, including the role of Sitka spruce.

423. Dietrichson, Jon.
1961. Bruker vi mellomeuropeiske provenienser riktig? [Are central European provenances being used correctly in Norway?] Norsk Skogbruk 7(2): 67-70, illus. [In Norwegian.]

Discusses the resistance of various provenances to autumn frosts and summarizes briefly studies on the date of completion of growth of pine, spruce, Douglas-fir, Sitka spruce, and western hemlock.

424. Dinwoodie, J. M.
1962. Some ring-width patterns in Sitka spruce timber from North America. Forestry 35(1): 22-26.

Variations in ring-width pattern of Sitka spruce through most of its life in its natural habitat are demonstrated from photographs of 10 cross sections. It is suggested that, besides being subject to the annual fluctuations in growth due to climatic variation, the tree in the natural forest is subject to periodic suppression and release, and that it has considerable powers of recovery. In plantations, therefore, Sitka spruce should respond to thinnings made even late in the rotation. (From author's summary.)

425. _____
1963. Variation in tracheid length in *Picea sitchensis* (Carr.). Great Brit. Dep. Sci. & Ind. Res. Forest Prod. Res. Spec. Rep. 16, 55 pp., illus.

Presents the results of an investigation into the variation in tracheid length in Sitka spruce within the annual ring, within the tree, and between trees of different provenances.

426. _____ and Richardson, S. D.
1961. Studies on the physiology of xylem development. Part II: some effects of light intensity, day length and provenance on wood density and tracheid length in *Picea sitchensis*. J. Inst. Wood Sci. 7: 34-47.

Experiments confirm a previous conclusion that wood density is a function of net assimilation rate, though the effect of low light intensities requires further experimental analysis. Tracheid length appears to be partly determined by the activity of the apical meristem, but there may be more direct effects of temperature and light on tracheid size. The way these factors operate is not yet clear.

427. Dixon, Dorothy.
1961. These are the champs. Amer. Forests 67(2): 41-47.

The largest Sitka spruce is listed as 51 feet, 6 inches in circumference at 4-1/2 feet above the ground, 180 feet tall, and with a crown spread of 50 feet. Location is in the Olympic National Park, Washington.

428. Dodwell, Arthur, and Rixon, Theodore F.
1900. The Olympic forest reserve, Washington. *In* First annual 1899-1900, Part V, forest reserves. U.S. Geol. Surv. 208 pp., illus. (With folded maps.)

429. Dominik, Jan.
1966. Obserwacje nad uszkadzaniem przez owady niektorych gatunkow drzew obcego pochodzenia, rosnacych w lasach doswiadczalnych sggw w Rogowie. [Observations on insect damage to certain exotic tree species in the experimental forests of the Warsaw Agricultural University at Rogow.] Folia Forest. Pol. (Les.) Ser. A12, 175-184. [In Polish.]

430. Doran, William L.
1957. Propagation of woody plants by cuttings. Univ. Mass. Coll. Agr. Exp. Sta. Bull. 491, 99 pp.

Sitka spruce cuttings from current-year wood taken in late winter rooted 100 percent in sand when treated with I.B.A. at 25 milligrams per liter for 24 hours, but not so well when untreated or when taken in the fall.

431. Douglas, David.
1914. Journal kept by David Douglas during his travels in North America, 1823-1827. 364 pp. London: William Wesley & Son.

Describes Sitka spruce under the name *Pinus menziesii*.

432. Douglas Fir Plywood Association.
1960. A recorded voluntary standard of the trade, commercial standard CS 122-60, for western softwood plywood. Ed. 4, 19 pp., illus.

433. Douglass, Bernard S.
1960. Collecting forest seed cones in the Pacific Northwest. USDA Forest Serv. Reg. 6, 21 pp., illus.

Includes practical information on cone collection, testing, and storage for several species including Sitka spruce.

434. Dowell, M. H. D.
1956. The influence of shade on certain tree seedlings, with particular reference to the regeneration of beech. J. Oxford Univ., Forest. Soc. Ser. 4, 4: 32-42.

The effect of decreasing light intensity on tree seedlings was investigated. Root competition was controlled and soil conditions were maintained at optimum level. One-year-old transplants of Sitka spruce and several other species were grown at Kennington Nursery, Oxford, for 1 year in 4 degrees of shade; 0 percent, 34 percent, 54 percent, and 78 percent of the light being excluded. Measurements were made of dry-weight increments, height growth, root/shoot ratios, mortality, leaf weights and lengths. Weed growth was also assessed.

435. Downing, G. L.
1959. Biological evaluation of an Alaska spruce beetle infestation in spruce stands on the Kenai Ranger District. USDA Forest Serv. Alaska Forest Res. Center Forest Insects Surv. Rep. 4, 5 pp.

436. _____
1959. Biological evaluation of the black-headed budworm and hemlock sawfly in the hemlock-spruce stands of southeast Alaska--season of 1959. USDA Forest Serv. Alaska Forest Res. Center Forest Insects Surv. Rep. 5, 3 pp.

437. Downs, Robert Jack.
1962. Photocontrol of growth and dormancy in woody plants, pp. 133-148, illus. *In* Tree growth, Theodore T. Kozlowski [ed.]. New York: Ronald Press Co.

Describes the effect of photoperiod on several species in the Pinaceae, including Sitka spruce. Under the experimental conditions described, Sitka spruce stopped growth on photoperiods of 14 hours or less.

438. Doyle, D. V., McBurney, R. S., and Drow, J. T.
1962. The elastic properties of wood: the moduli of rigidity of Sitka spruce and their relations to moisture content. USDA Forest Prod. Lab. Rep. 1528-B, 7 pp. plus 3 tables, 4 figs.

439. Drew, John, and Pylant, G. D., Jr.
1966. Turpentine from the pulpwoods of the United States and Canada. Tappi 49: 430-438, illus.

Samples of wood chips representing the common species of trees utilized in the pulp and paper industry of the U.S. and Canada were tested to determine yield and composition of volatile turpentine. Sitka spruce yielded 0.12 gallon per ton of dry wood. The main components of the turpentine are described.

440. Drow, J. T.
1945. Effect of hydraulic-equipment oils on the bending and compressive strength of Sitka spruce. USDA Forest Prod. Lab. Rep. 1520, 8 pp. plus 7 tables, 2 figs.

441. _____ and McBurney, R. S.
1946. The elastic properties of wood. Young's moduli and Poisson's ratio of Sitka spruce and their relations to moisture content. USDA Forest Prod. Lab. Rep. 1528-A, 11 pp., illus.

442. Drow, John T.
1945. Effect of moisture on the compressive, bending, and shear strengths, and on the toughness of plywood. USDA Forest Prod. Lab. Rep. 1519, 12 pp., illus.

443. Duffield, John W.
1950. Review of "Sur Quatre Hybrides de Genres Chez les Abietinees," by Mme. Van Campo-Duplan and H. Gaussen. [On four inter-genus hybrids in the Abietineae.] J. Forest. 48: 440.

Discusses the credibility of the hypothesis presented in the article reviewed, that *Tsuga mertensiana* originated as a cross between *Picea* and *Tsuga*.

444. _____
1956. Damage to western Washington forests from November 1955 cold wave. USDA Forest Serv. Pacific Northwest Forest & Range Exp. Sta. Res. Note 129, 8 pp., illus.

The mid-November cold wave that occurred throughout the Pacific Northwest caused serious damage to western Washington forests. Western hemlock and western redcedar were damaged most heavily and Douglas-fir somewhat less. Sitka spruce was not damaged seriously, and injury to true firs was slight.

445. _____ and Eide, Rex P.
1950. Polyethylene bag packaging of conifer planting stock in the Pacific Northwest. J. Forest. 57: 578-579.

Douglas-fir, noble fir, grand fir, Pacific silver fir, Sitka spruce, Port-Orford cedar, and western hemlock seedlings are being successfully stored and shipped in kraft-polyethylene bags at the Col. W. B. Greeley Forest Nursery, Nisqually, Wash.

446. Duguid, James D.
1946. Notes on forestry in the Isle of Man. Scot. Forest. J. 60(2): 77-85.

Gives notes on the relative merits of the various species planted by the Forestry Commission. An essential quality is good wind resistance, and Sitka spruce is particularly satisfactory.

447. Dunford, Earl Gerald.
1936. The application of the diameter limit system of cutting to Sitka spruce. 61 pp., illus. (M.S. thesis on file at Yale Univ. Sch. Forest.)

448. Dunn, Malcom.
1892. The value in the British Islands of introduced conifers. J. Roy. Hort. Soc. 14: 73-102.

Abies menziesii (Menzies spruce) or, as it is now called by botanists, *Picea sitchensis*, was introduced by Douglas in 1831. The finest tree recorded in Scotland grows at Castle Menzies and is 46 years old; 96 feet, 6 inches high; and 11 feet in girth. The species was named by Douglas after Archibald Menzies, who first discovered it when accompanying Vancouver on his voyage around the world. Heights and diameters of especially large trees in Britain are mentioned.

449. Durrell, L. W.
[n.d.] Notes on some North American conifers based on leaf characters. Iowa State Coll., Dep. Bot. Contrib. 66: 519-582.

450. Dutton, G. G. S., and Hunt, K.
1958. The constitution of the hemicelluloses of Sitka spruce (*Picea sitchensis*). I. Composition of the hemicellulose and identification of 2-O-(4-O-methyl-D-glucopyranosiduronic acid)-D-xylose. J. Amer. Chem. Soc. 80: 4420-4422.

451. _____ and Hunt, K.
1958. The constitution of the hemicelluloses of Sitka spruce (*Picea sitchensis*). II. Structure of the mannan portion. J. Amer. Chem. Soc. 80: 5697-5701.

Discusses the structural features of glucomannans extracted from the hemicellulose of Sitka spruce.

452. _____ and Hunt, K.
1960. The constitution of the hemicelluloses of Sitka spruce (*Picea sitchensis*). III. Structure of an Arabomenthoxyglucuronoxylan. J. Amer. Chem. Soc. 82: 1682.

453. Eades, H. W.
1932. British Columbia softwoods, their decays and natural defects. Can. Dep. Int. Forest Serv. Bull. 80, 126 pp., illus.

454. _____
1958. Differentiation of sapwood and heartwood in western hemlock by color tests. Forest Prod. J. 8: 104-106.

Perchloric acid, Benedict's solution, or Fehling's solution may be used for Sitka spruce. Reagents for other softwood species, including true firs, Douglas-fir, western redcedar, lodgepole pine, and western hemlock, are described.

455. Eastwood, Alice.
1905. A handbook of the trees of California. Calif. Acad. Sci. Occas. Pap. 9, 86 pp., illus.

456. Edlin, H. L.
1953. The forester's handbook. 394 pp. plus 31 photos. London: Thames & Hudson.

Includes a general description of Sitka spruce in Britain.

457. _____
1964. Forestry in Great Britain. Great Brit. Forest. Comm., 28 pp., illus.

Contains a historical review of forestry in Great Britain and describes present forest policy, with a short review of each of the principal trees grown, including site requirements and statistics. Sitka spruce is the most widely planted exotic conifer in Britain because of its resistance to exposure at high elevations or near the sea, its tolerance to acid peats or heathy vegetation, and its rapid timber production. However, it is susceptible to frost damage in valley bottoms. Rapid height growth is common; many trees exceed 100 feet in 30 years. The timber closely resembles that of Norway spruce. Sitka spruce plantations covered 167,000 acres in 1947; the Forestry Commission plants about 17,000 acres annually.

458. Edlin, Herbert L.
1962. A modern sylva or a discourse of forest trees. 3. The spruces. Quart. J. Forest. 56(4): 292-300.

459. _____ (Ed.)
1964. Forest practice: a summary of methods of establishing forest nurseries and plantations with advice on other forest questions for owners, agents, and foresters. Great Brit. Forest. Comm. Bull. 14, 103 pp.

460. _____
1965. Know your conifers. Great Brit. Forest. Comm. Booklet 15, 56 pp., illus.

461. Edwards, M. V.
1952. The effects of partial soil sterilization with formalin on the raising of Sitka spruce and other conifer seedlings. Great Brit. Forest. Comm. Forest Rec. 16, 20 pp., illus.

Summarizes 5 years of experimental work and reports experimental data. The best commercial formalin treatment was found to be one-tenth gallon per square yard, diluted with nine to 24 times its volume of water. Under proper conditions, treatment increased the growth of first-year seedlings and reduced the growth of weeds. Adverse effects on seedlings were rare. Costs are discussed.

462. _____
1953. Frost damage to Sitka spruce plants in the nursery and its relation to seed origin. Scot. Forest. 7(2): 51.

In Scotland, Sitka spruce from Queen Charlotte Islands is more resistant to frost than plants of U.S. origin. Experience with seedlings from seed collected in older Sitka spruce woods in Scotland suggests that many of these woods are of U.S. provenance.

463. _____
1959. Use of triple superphosphate for forest manuring. *In* Report on forest research for the year ended March 1958. Great Brit. Forest. Comm., pp. 117-130. London: H. M. Stationery Office.

464. _____
1962. The progress of peat land afforestation in Britain. Irish Forest. 19(1): 102-109.

Attempts to raise mixtures of species on peat lands are now less frequent. Lodgepole pine either pure or with a mixture of Japanese or hybrid larch or *Tsuga* rather than Sitka spruce is planted. Several trial forests are being established in the north of Scotland where blanket bog is the prevailing formation.

465. _____ and Holmes, G. D.
1950. Experimental work in the nursery. *In* Report on forest research for the year ended March 1949. Great Brit. Forest Comm., pp. 35-43. London: H. M. Stationery Office.

466. _____ and Holmes, G. D.
1951. Experimental work in the nursery. *In* Report on forest research for the year ended March 1950. Great Brit. Forest. Comm., pp. 12-24. London: H. M. Stationery Office.

467. _____ and Holmes, G. D.
1957. Problems in afforestation. *In* Report on forest research for the year ended March 1956. Great Brit. Forest. Comm., pp. 36-39. London: H. M. Stationery Office.

At Croft Pascoe, on the exposed Lizard Peninsula of Cornwall, afforestation experiments on soils derived from serpentine rock have made a promising start. Broom grows vigorously and will be a useful nurse. Of the many tree species tried, Sitka spruce, lodgepole pine (coastal provenance), *Pinus radiata*, and *P. pinaster* show good early growth.

468. _____, Steward, G. G., and Herman, D. W.
1960. Silvicultural investigations in the forest: (B) Scotland and north England. *In* Report on forest research for the year ended March 1959. Great Brit. Forest. Comm., pp. 38-43. London: H. M. Stationery Office.

Analysis of Norway and Sitka spruce trees blown down in the Inverliever pruning experiments, started 19 years ago, showed no ill effects from the pruning of live branches and illustrated again how thin was the layer of knot-free timber produced during that period. This emphasized the necessity of pruning only the largest, most vigorous trees in a crop, and of starting pruning when their breast-height diameter is about 4 inches (earlier than brashing is usually done).

469. Eire Minister of Lands and Forestry.
1944. Report for the period from 1st April, 1938 to 31st March, 1943. 65 pp.

Armillaria mellea was the most troublesome fungus during the period under review, especially on Sitka spruce.

470. Eis, Slavoj.
1962. Statistical analysis of several methods for estimation of forest habitats and tree growth near Vancouver, B.C. Univ. Brit. Columbia Fac. Forest. Bull. 4, 76 pp., illus.

The analysis includes the hemlock-Sitka spruce type on the southern fringe of the coastal mountain range between Alouette Lake and Howe Sound below the 300-foot elevation. Plant communities were used as a basis for separation of biologically equivalent forest habitats. It was found that almost all the variability of the plant communities studied could be accounted for by differences in soil and in moisture regime. Using only a few environmental characteristics, it was possible to predict both site index and plant community with an accuracy approaching the result obtained using many factors. Mathematical formulas for predicting site index were calculated.

471. Eliot, W. A., and McLean, G. B.
1948. Forest trees of the Pacific coast. New ed., 565 pp., illus. New York: G. P. Putnam's Sons.

472. Elliott, G. K.
1960. The distribution of tracheid length in a single stem of Sitka spruce. J. Inst. Wood Sci. 5: 38-47.

Examines the pattern of variation within a 41-year stem. The variation radially from the pith outward and longitudinally from the stump upward followed the expected pattern laid down in Sanio's laws. A comparison between the effect of age and ring width on tracheid length showed that age had the stronger effect. From a 68-year cross section of another Sitka spruce, age was shown to have a significant effect on tracheid length only in the early years; as the tree matures the effect of age is superseded by that of ring width. (From author's summary.)

473. Ellis, Everett L.
1964. Inorganic elements in wood, pp. 181-189, illus. *In* Cellular ultrastructure of woody plants, Wilfred A. Cote [ed.]. Advance. Sci. Seminar Pinebrook Conf. Center Proc. Syracuse: Syracuse Univ. Press.

474. Elton, E. T. G.
1950. *Dendroctonus micans* Kugel., a pest of Sitka spruce in the Netherlands. Eighth Int. Congr. Entomol. Proc. 1948: 759-764.

Since its appearance in the Netherlands in 1935, *D. micans* has generally been found as a primary pest on Sitka spruce. Natural enemies have so far rarely been found attacking it and are unlikely to give complete control. The rotation period of the tree will probably be limited to about 40 years by *D. micans* attack.

475. Embry, R. S.
1963. Prescribed burning for seedbed improvement. Thirteenth Alaska Annu. Sci. Conf. Proc. 1962: 88.

476. Embry, Robert S.
1964. What happens to nonmerchantable trees left after clearcutting? Northern Forest Exp. Sta. USDA Forest Serv. Res. Note NOR-7, 3 pp.

The study indicated a 5-year survival rate of 51 percent. Wind and logging damage caused greatest mortality. Diameter growth was good, but height growth was poor. Trees produced cones but the quality and quantity of seed are not known.

477. _____ and Haack, Paul M.
1965. Volume tables and equations for young-growth western hemlock and Sitka spruce in southeast Alaska. Northern Forest Exp. Sta. USDA Forest Serv. Res. Note NOR-12, 21 pp.

478. Enari, Leonid.
1956. Plants of the Pacific Northwest. 315 pp., illus. Portland, Oreg.: Bindfords & Mort.

479. Enderlein, Horst, and Vogl, Michael.
1966. Experimentelle untersuchumgen uber die SO_2 - empfindlickeit der Nadeln verschiedener Koniferen. [Experimental observation of the SO_2 resistance of various conifer needles.] Arch. Forstwesen 15(11/12): 1207-1224, illus. [In German. English summary.]

480. Engelhardt, N. T.
1957. Pathological deterioration of looper-killed western hemlock on southern Vancouver Island. Forest Sci. 3: 125-136.

481. Englerth, George H.
1947. Decay of Sitka spruce in southeastern Alaska. J. Forest. 45: 894-900, illus.

Decay was studied in 630 trees on 11 plots. Data on age and size of trees and kinds and amounts of decay were recorded. The more important fungi found on living Sitka spruce were *Polyporus schweinitzii*, *P. borealis*, *P. sulphureus*, *Fomes pinicola*, *F. pini*, *F. officinalis*, and *Lentinus kaufmannii*. Sporophores of these fungi, excepting *F. pini*, were produced infrequently or not at all on living trees. No swollen knots were observed in association with *F. pini* infections. In most cases, frost cracks, injuries caused by falling trees, or broken tops provided the only indication of the presence of decay.

482. Erickson, R. W., and Hossfeld, R.
1964. Effect of cationic and nonionic fluorocarbon surfactants on the permeability of wood to water. Tappi 47: 792-795, illus.

Sitka spruce was used as the experimental material.

483. Erteld, W.
1953. Uber die zukünftige Arbeit auf dem Gebiet der Ertragskunde. [Future work in the study of yield.] Arch. Forstwesen 2(4/5): 432-442. [In German.]

484. _____
1960. Bericht uber das in der Zeit vom 21.bis 28.9, 1959 in Eberswalde abgehaltene Ertragskundliche Symposium. [Report on the yield-studies symposium at Eberswalde, Sept. 21-28, 1959.] Arch. Forstwesen 9(4): 305-325. [In German.]

485. Eule, H. W.
1962. Forschungsbeiträge zur forstlichen Photogrammetrie II. Das Verhältnis der Kronengrösse zum Brusthöhendurchmesser und zur Derbholzmasse an Einselstämmen. [The relation of crown size to d.b.h. and volume of individual stems.] Allg. Forstzeitschrift 17(1/2): 31-33. [In German.]

Describes preliminary measurements of Sitka spruce and beech in mixture with even-aged or older Scots pine or oak. When the trees were divided into height classes, correlations between crown diameter and diameter breast height were fairly close for both species; correlations with volume were even closer and approached linearity.

486. Evan, W. David D.
1952. Afforestation of wasteland. J. Land Agents Soc. 51(1): 43-44.

Describes the successful afforestation of spoil banks from a sand and gravel quarry with Sitka spruce and unrooted cuttings of *Populus robusta*.

487. Evans, Russell Stewart.
1951. Studies on holocellulose of Sitka spruce; dilute acid hydrolysis. 40 pp. (M.S. thesis on file at Univ. Brit. Columbia.)

488. Eyre, Samuel Robert.
1963. Vegetation and soils, a world picture. 324 pp., illus. Chicago: Aldine Publishing Co.

489. Fabricius, O.
1926. Douglas- og Sitkagran. [Douglas and Sitka spruce.] Dansk Skovforenings Tidsskr. 3: 405-541. [In Danish.]

Describes experience with Sitka spruce planted in Denmark.

490. Fagerlund, Gunnar O.
1965. Olympic National Park - Washington. U.S. Dep. Int. Nat. Park Serv. Natur. Hist. Handbook 1, 60 pp., illus.

Describes Sitka spruce in the park. The species is common only in the rain forest on the west side. Large trees are 225 to 300 feet tall and 5 to 8 feet in diameter. The largest known specimen is 13 feet, 4 inches in diameter, located about 4 miles above the Hoh Ranger Station.

491. Fairbairn, W. A.
1966. Measurements of light intensity. *In* Report on forest research for the year ended March 1965. Great Brit. Forest. Comm., p. 131. London: H. M. Stationery Office.

Describes light intensity measured in openings of various sizes in several Sitka spruce stands in Britain.

492. _____
1967. Light relation of six tree species in the nursery and in the forest. *In* Report on forest research for the year ended March 1967. Great Brit. Forest. Comm., pp. 154-155. London: H. M. Stationery Office.

493. Farquhar, J.
1966. The use of seedlings for forest planting in Scotland and north England. *In* Report on forest research for the year ended March 1965. Great Brit. Forest. Comm., pp. 154-168. London: H. M. Stationery Office.

Survival and height growth of 1-year seedlings of several species including Sitka spruce were poorer than for transplants, and results were less reliable. The use of 1-year seedlings is not recommended.

494. Farrer, R. P.
1951. The use of selective herbicides in forestry in general and in nursery work in particular. Empire Forest. Rev. 30(1): 66-71.

495. Faulkner, R.
1955. Experiments on applying various forms of nitrogen to Sitka spruce seedbeds in Scotland. *In* Report on forest research for the year ended March 1954. Great Brit. Forest. Comm., pp. 91-101. London: H. M. Stationery Office.

Summarizes long-term fertilization trials using nitrochalk, flash, formalized casein, and other materials. Of those tested, nitrochalk was considered most suitable and economical for seedbeds.

496. _____
1956. Green crops compared with hopwaste as heathland nursery treatments. Great Brit. Forest. Comm. Res. Br. Pap. 19, 10 pp.

Experiments carried out with Sitka spruce showed that, in the first year on new heathland or woodland nursery sites, the main limiting factors to seedling growth are lack of N, P, and K. They also showed that a first-year green crop of oats, grown with the aid of artificial fertilizers and followed by seedbed dressings of NPK fertilizers at standard rates, can provide a stimulus to Sitka spruce seedlings equal to and more consistent than that provided by compost followed by similar rates of NPK fertilizer. Comparative costs and benefits are discussed.

497. _____
1957. Experiments on seedbed compaction. *In* Report on forest research for the year ended March 1956. Great Brit. Forest Comm., pp. 113-123. London: H. M. Stationery Office.

Investigates the effect of various degrees of seedbed compaction, before and after sowing, on height growth and total yield of seedlings. Sitka spruce was used in all tests. The results indicate that compaction with a roller before sowing gives maximum yield of seedlings. Compaction hastens germination but does not greatly affect height growth. Slightly firming the seed into the seedbed surface and rolling after applying grit covers have little effect on growth and yield of seedlings.

498. _____
1957. The storage of one-year conifer seedlings. *In* Report on forest research for the year ended March 1956. Great Brit. Forest. Comm., pp. 85-95. London: H. M. Stationery Office.

499. _____
1958. Investigations into intensive methods of raising conifer seedlings. Empire Forest. Rev. 37(1): 85-95.

Trials in Scotland showed that four crops of Sitka spruce seedlings per year could be raised in a frame with soil temperature (at 2 inches) maintained at 65-70°F. and with artificial illumination extended into the night, but because of difficulties in hardening-off the seedlings, it is impracticable to raise more than two or three crops per year.

500. _____
1958. Scottish experiments comparing chloropicrin with formalin as a partial soil sterilizer for conifer seedbeds. *In* Report on forest research for the year ended March 1957. Great Brit. Forest. Comm.. pp. 159-170. London: H. M. Stationery Office.

Summarizes the results of experiments started in 1953 at a number of nurseries. It was found that chloropicrin injected into nursery beds is usually a slightly more effective sterilizing agent than formalin, as shown by height growth and yield of usable 1-year seedlings of Sitka spruce. Time of application and costs are discussed.

501. _____
1958. Summer, autumn or spring lining out? Scot. Forest. 12(3): 127-134.

June and July lining out gave a higher yield of usable transplants and compared favorably with March, the usual period. Lining out in late autumn gave the lowest numbers of usable transplants.

502. _____
1960. Summary of recent research into phosphate and potash manuring of conifers in nursery seedbeds in Scotland and northern England. *In* Report on forest research for the year ended March 1959. Great Brit. Forest. Comm., pp. 126-140. London: H. M. Stationery Office.

Summarizes the results of a long series of experiments. There is no danger in applying P or K fertilizers on the day of sowing if they are well mixed with the soil. Equally good results are obtained if applied earlier, up to 16 weeks before sowing. The currently recommended rate of 14 pounds of superphosphate per 100 square yards of nursery bed is satisfactory for Japanese larch, western hemlock, and Douglas-fir, but for Sitka spruce 1-1/2 to 2 times this amount is recommended. For all four species, applications of K_2SO_4 at 4 to 5 pounds per 100 square yards are generally adequate.

503. _____
1960. Summary of recent research into nitrogen manuring of conifers in nursery seedbeds in Scotland and northern England. *In* Report on forest research for the year ended March 1959. Great Brit. Forest. Comm., pp. 141-160. London: H. M. Stationery Office.

504. _____
1965. Seed orchards in Britain. *In* Report on forest research for the year ended March 1964. Great Brit. Forest. Comm., pp. 211-218. London: H. M. Stationery Office.

505. _____
1967. Procedures used for progeny-testing in Britain with special reference to forest nursery practice. Great Brit. Forest. Comm. Forest Rec. 60, 22 pp., illus.

506. _____ and Aldhous, J. R.
1956. Nursery investigations. *In* Report on forest research for the year ended March 1955. Great Brit. Forest. Comm., pp. 16-32, illus. London: H. M. Stationery Office.

507. _____ and Aldhous, J. R.
1957. Nursery investigations. *In* Report on forest research for the year ended March 1956. Great Brit. Forest. Comm., pp. 19-35. London: H. M. Stationery Office.

508. _____ and Aldhous, J. R.
1957. Nursery investigations. *In* Report on forest research for the year ended March 1957. Great Brit. Forest. Comm., pp. 19-36. London: H. M. Stationery Office.

509. _____ and Aldhous, J. R.
1959. Nursery investigations. *In* Report on forest research for the year ended March 1958. Great Brit. Forest. Comm., pp. 20-37. London: H. M. Stationery Office.

510. _____ and Aldhous, J. R.
1960. Nursery investigations. *In* Report on forest research for the year ended March 1959. Great Brit. Forest. Comm., pp. 18-32. London: H. M. Stationery Office.

511. _____, Herbert, R. B., and Fletcher, A. M.
1965. Forest genetics. *In* Report on forest research for the year ended March 1964. Great Brit. Forest. Comm., pp. 53-56. London: H. M. Stationery Office.

512. _____, Herbert, R. B., and Fletcher, A. M.
1966. Forest genetics. *In* Report on forest research for the year ended March 1965. Great Brit. Forest. Comm., pp. 59-60. London: H. M. Stationery Office.

A total of 131 candidate Sitka spruce plus trees have been selected. Sitka spruce has been a difficult species to propagate from cuttings or by grafting. Recent results from August-September tests showed 60-percent rooting of cuttings taken from the 12th internode from the top of the trees and treated with a mild indole acetic acid rooting hormone powder.

513. _____, Herbert, R. B., and Fletcher, A. M.
1967. Forest genetics. *In* Report on forest research for the year ended March 1966. Great Brit. Forest. Comm., pp. 66-69. London: H. M. Stationery Office.

514. _____, Herbert, R. B., and Fletcher, A. M.
1967. Forest genetics. *In* Report on forest research for the year ended March 1967. Great Brit. Forest. Comm., pp. 91-95. London: H. M. Stationery Office.

A total of 332 candidate Sitka spruce plus trees have been selected, and propagation in tree banks by grafting is now keeping abreast of the rate of selection. A national tree bank was started at Wauchope Forest, Roxburghshire, Scotland. Data on success of vegetative propagation are given. An attempt to grow Sitka spruce progenies under glass for more than one growing season was unsuccessful because plants developed abnormally in the second year. The problem appears to be associated with a winter-chilling requirement.

515. _____ and Holmes, G. D.
1952. Experimental work in nurseries: composting and trials of composting. *In* Report on forest research for the year ended March 1951. Great Brit. Forest. Comm., pp. 20-21. London: H. M. Stationery Office.

516. _____ and Holmes, G. D.
1954. Experimental work in nurseries. *In* Report on forest research for the year ended March 1953. Great Brit. Forest. Comm., pp. 17-31. London: H. M. Stationery Office.

517. Faull, J. H.
1934. A remarkable spruce rust, *Peridermium parksianum* n. sp. J. Arnold Arboretum 15: 86-87.

518. Fensom, K. G.
1959. The characteristics and significance or spruce. Can. Forest Prod. Lab., 22 pp. plus 4 tables.

Discusses identification, mechanical and chemical properties, uses (including drying and preservation), potential demand, etc., for five species of spruce including Sitka spruce.

519. Fernow, B. E.
1902. The forests of Alaska. Forest & Irrig. 8: 66-70.

520. _____
1910. The forests of Alaska. *In* History, geography, resources, Harriman Alaska Series, Vol. 2. Smithsonian Inst. Pub. 1991, pp. 235-256, illus. (Formerly privately printed in 1902 as Harriman Alaska Expedition, New York: Doubleday Page & Co.)

521. Ferré, Y. de.
1952. Les formes de jeunesse des Abiétacees: ontogénie-phylogénie. [The form, ontogeny, and phylogeny of young *Abies*.] Fac. Sc. Toulouse, vol. 1, et Trav. Lab. Forest de Toulouse tome 2, vol. 3, art. 1, 282 pp., illus. [In French.]

Describes purported intergeneric cross: *Picea sitchensis* X *Tsuga heterophylla*.

522. Finch, H. D. S.
1957. New ways of using the general tariff tables for conifers. Great Brit. Forest Res. Forest. Comm. Rec. 32, 11 pp.

523. Findlay, W. P. K.
1934. Studies in the physiology of wood-destroying fungi. The effect of nitrogen content upon the rate of decay of timber. Ann. Bot. (London) 48: 109-117.

Low concentration of ammonium nitrate slightly increased the rate of decay of blocks of Sitka spruce heartwood. Addition of an organic source of nitrogen markedly increased fungal growth.

524. Fitzpatrick, H. M.
1965. Conifers: keys to the genera and species, with economic notes. Roy. Soc. Sci. Proc. (Dublin) 2(7): 67-129 plus 6 plates.

525. Flensborg, C. E.
1950. Fra Islands Skovsag. [Forestry in Iceland.] Hedeselskabets Tidsskr. Viborg 71(3): 47-59, illus. [In Icelandic.]

Describes the progress of forestry in Iceland during the last 50 years and gives details of some experimental plantings including Sitka spruce.

526. Fligg, D. M.
1960. Imperial yield tables. Brit. Columbia Forest Serv. Forest Surv. Note 6, 13 pp. plus tables.

Tables presented are based on additional information and supplement those included in the 1957 continuous forest inventory of British Columbia.

527. _____ and Breadon, R. E.
1959. Log position volume tables. Brit. Columbia Forest Serv. Forest. Surv. Note 4, 8 pp. plus tables.

Presents regional information on the average cubic-foot volume in 32-foot logs, according to their position in trees, of five conifer species, including Sitka spruce, by diameter and total height. Also indicates possible log grade, according to size requirements only, for each log position in trees of varying species, and size.

528. Flohr, W.
1959. Waldbauliche Richtlinien für die Bewirtschaftung der Wälder im mecklenburgischen Grund- und Endmoränengebiet. [Correct silviculture for the management of the forest of the ground-and-end morain region of Mecklenburg.] Arch. Forstwesen 8(2): 85-160. [In German. English summary.]

529. Forbes, A. C.
1914. The Sitka spruce in Ireland. Roy. Scot. Arboricult. Soc. Trans. 28(2): 264-265.

530. Forest Club, University of British Columbia.
1959. Forestry handbook for British Columbia. 800 pp., illus. Vancouver: Univ. Brit. Columbia.

Pages 567-568 list silvical characteristics of Sitka spruce.

531. Foster, R. E., and Foster, A. T.
1953. Estimating decay in western hemlock: suggested aids to the management of mature hemlock-spruce forest on the Queen Charlotte Islands. Brit. Columbia Lumberman 37(10): 42-47, illus.

532. Fowells, H. A. (Comp.).
1965. Silvics of forest trees of the United States. U.S. Dep. Agr. Handbook 271, 762 pp., illus.

Contains a summary of information on the silvics of Sitka spruce, including its relationship to climate, soils, topography, and associated species and a description of its life history from seedling stage to maturity.

533. Francke-Grosmann, H.
1948. Rotfäule und Riesenbastkäfer, eine Gefahr fur die Sitkafichte auf Öd-und Ackerlandaufforstungen Schleswig-Holsteins. [Red rot and giant bark beetle, a threat to Sitka spruce in afforestations on waste and arable land in Schleswig-Holstein.] Forst- und Holzwirtsch. 23: 232-235. [In German.]

Sitka spruce was more severely infected by *Fomes annosus* than was *Picea abies*. The invasion of a single main root is followed by exudation of resin on the bark of the trunk and thinning of the crown. Infection makes the trees more susceptible to attack by *Dendroctonus micans*.

534. _____
1954. Populations dynamische Faktoren bei der Massenvermehrung des *Dendroctonus micans* Kug. an der Sitkafichte in Schleswig-Holstein. [Factors affecting mass outbreaks of *D. micans* on Sitka spruce in Schleswig-Holstein.] Verhandl. Deut. Ges. angew. Entomol. e. V. (Frankfurt A. M.) 1952: 108-117, illus. [In German.]

Describes insect parasites on a pest which attacks chiefly trees weakened by *Fomes annosus*. Discusses dry weather and enemies as possible causes of population fluctuations. No relation was found between susceptibility to attack and stand density or light conditions.

535. _____
1954. Feinde und Krankheiten der Sitkafichte auf nordeutschen Standorten. [Pests and diseases of Sitka spruce on north German sites.] Forst- und Holzwirtsch. 9 A [6]: 117-119. [In German.]

536. _____
1954. Über Wurzel - und Stockfäulen der Sitkafichte auf norddeutschen Standorten. [About root and stem rots of Sitka spruce on north German sites.] Eleventh Congr. Int. Union Forest Res. Organ. Proc. (Rome) 1953, sect. 24, no. 2/2, pp. 649-655. [In German.]

537. _____
1956. Kleinschmetterlinge als Schadlinge der Sitkafichten auf Standorten Schleswig-Holsteins. [Small lepidoptera as pests of Sitka spruce on sites in Schleswig-Holstein.] Twelfth Congr. Int. Union Forest. Res. Organ. Proc. (Oxford) 1956: 192-194. [In German.]

Reports on injuries to terminal shoots in 8- to 15-year-old Sitka spruce plantations by *Dioryctria abietella*, and to lateral shoots in a 15-year-old plantation by *Steganoptycha ratzeburgiana*, both observed on the island of Fohr.

538. _____
1962. Ungewohnliche knospenschaden an Sitkafichten. [Unusual injuries to buds of Sitka spruce.] Eleventh Int. Congr. Entomol. Proc. 1960 (2): 189-191. [In German.]

Describes injuries caused by *Lygus rubicatus* (a mirid) and *Trisetacus grosmanni* (a recently discovered eriophyid) in Schleswig-Holstein.

539. _____ and Ruhm, W.
1954. Die Bekampfung des Riesenbastkafers (*Dendroctonus micans* Kug.). [The control of *D. micans*.] Z. Weltforstwirtschaft 17(2): 48-53, illus. [In German. English summary.]

Outlines the occurrence of *D. micans* on *Picea glauca*, *P. abies*, and *P. sitchensis* in Schleswig-Holstein, its biology, habits, and symptoms of attack, and discusses chemical control. The felling and debarking of infested trees has proved ineffective.

540. Francke-Grosmann, Helene.
1950. Die gefährdung der Sitkafichte durch rotfäule (*Fomes annosus* Fr.) und riesenbastkäfer (*Dendroctonus micans* Kug.) in aufforstungsrevieren Schleswigs. [Danger to Sitka spruce from *F. annosus* and *D. micans* in afforestation areas of Schleswig.] Eighth Int. Congr. Entomol. Proc. 1948: 773-778 plus 2 photos. [In German.]

Discusses the status of *D. micans* as a primary and secondary (succeeding *F. annosus*) pest of Sitka spruce and describes the progress of the attack.

541. _____
1950. Uber ein Massenvorkommen von *Gilletteella*-Gallen an Sitkafichten (*Picea sitchensis* Carr.). [An outbreak of *Gilletteella* galls on Sitka spruce.] Anz. Schadlingskunde 23(1): 3-6, illus. [In German.]

542. Frankland, Edward P.
1956. Dermatitis from handling conifers. Quart. J. Forest. 50(3): 244-245.

Records the occurrence of dermatitis in a worker in a Sitka spruce plantation.

543. Franklin, Jerry F.
1961. A guide to seedling identification for 25 conifers of the Pacific Northwest. USDA Forest Serv. Pacific Northwest Forest & Range Exp. Sta., 65 pp., illus.

Describes appearance of Sitka spruce seedlings at the end of their first growing season.

544. Fraser, A. I.
1962. The soil and roots as factors in tree stability. Forestry 35(2): 117-127.

Effects of drainage and peat depth on the rooting and stability of 34-year-old Sitka spruce were studied at Forest of Ae in Dumfries and Kielder Forest of Northumberland. It was concluded that relatively small increases in rooting depth obtained by drainage of peat soils can produce considerable increase in resistance to blowdown. Drainage also increased the mechanical strength of the soil. On a freely drained site, Sitka spruce developed a vertical root system, and it is not completely correct to consider it a shallow-rooted species.

545. _____
1965. Wind stability: tree-pulling investigations. *In* Report on forest research for the year ended March 1964. Great Brit. Forest. Comm., pp. 35-36. London: H. M. Stationery Office.

546. _____
1965. The uncertainties of wind-damage in forest management. Irish Forest. 22(1): 23-30.

Wind damage to Sitka spruce and other plantations in Britain can be reduced by recognition of high hazard areas and silvicultural treatment to reduce the hazard. Soil condition is a major factor in tree stability, and

soil mapping, particularly to identify poorly drained soils, is desirable. Soil drainage is recommended depending on age and height of plantations. Sitka spruce growing on deep soils should be thinned early and regularly.

547. _____ and Gardiner, J. B. H.
1967. Rooting and stability in Sitka spruce. Great Brit. Forest. Comm. Bull. 40, 27 pp., illus.

Describes investgations in north Wales and the English-Scottish borders. The effect of nutrients, drainage, stand characteristics, and topography are discussed.

548. _____ and Henman, D. W.
1966. Tree stability. *In* Report on forest research for the year ended March 1965. Great Brit. Forest. Comm., pp. 44-46. London: H. M. Stationery Office.

549. _____ and Neustein, S. A.
1967. Regeneration of tree stands. *In* Report on forest research for the year ended March 1967. Great Brit. Forest. Comm., pp. 55-59. London: H. M. Stationery Office.

550. _____ and Neustein, S. A.
1967. Tree stability. *In* Report on forest research for the year ended March 1967. Great Brit. Forest. Comm., pp. 74-76. London: H. M. Stationery Office.

551. _____ and Taylor, G. T. M.
1967. Cultivation and drainage. *In* Report on forest research for the year ended March 1966. Great Brit. Forest. Comm., pp. 43-47. London: H. M. Stationery Office.

552. Fraser, George K.
1936. Cairnhill Plantation, Durris: An example of variation in the rate of tree-growth resulting from differences in soil. Forestry 10: 110-123, illus., plus 2 plates.

553. Freas, A. D., and Selbo, M. L.
1954. Fabrication and design of glued laminated wood structural members. U.S. Dep. Agr. Tech. Bull. 1069, 220 pp., illus.

554. Freeman, Otis, and Upton, Rolland H.
1957. Washington State resources. 210 pp., illus. Seattle: Wash. State Resource Comm.

555. Frey, R. W., and Clarke, I. D.
1941. Tannin content of Sitka spruce bark. J. Amer. Leather Chem. Ass. 36: 576-584, illus.

The average tannin content of 31 samples of Sitka spruce bark from Washington and Oregon was 24.1 percent, the individual results varying from 11.2 to 37.2 percent. Tannin content was related both to position in tree and age of tree, increasing with height from the ground and, at least for bark near the butt end, decreasing with age of tree. The tannin is of the catechol type. Total sugars in the bark ranged from 3.3 to 12.4 percent,

increasing with height from the ground and decreasing slightly with age of tree. Sitka spruce bark is very thin and would give a low yield per tree, so a large volume of tanning extract could not be produced from this source alone.

556. Friedrich, Alexander Gunther.
1951. Untersuchungs-ergebnisse zum "Alten und Neuen" über die Sitkafichte (*Picea sitchensis* Carr.). [Results of past and present researches on Sitka spruce.] Forest- und Holz 6(3): 37-38. [In German.]

The susceptibility of Sitka spruce to attack by *Fomes annosus* and (subsequently) *Dendroctonus micans*, makes it inadvisable to plant it in mixture with other species also subject to *F. annosus* attack. In coastal areas with high rainfall, Sitka spruce gives good results when planted on windy and water-logged sites. Mixed stands on such sites should be well tended and watched for *F. annosus*.

557. Fröhlich, H. J.
1957. Züchtungsarbeiten im Lehrforstamt Gahrenberg. [Tree breeding in the Gahrenberg Instructional Forest.] Forstarchiv 28(8/9): 170-175, illus. [In German.]

Describes provenance trials, begun about 30 years ago, of several species, including Sitka spruce. Some growth data are given and a brief note is included on current aims in breeding work.

558. Froland, Age.
1962. Gjødsling av plantefelter på Vestlandet. Noen foreløpige resultater fra gjødslingsforsøkene i ytre strøk. [Initial fertilization of plantations in West Norway. Some preliminary results from experiments in the coastal districts proper.] Tidsskr. Skogbruk 70(1): 14-35, illus. [In Norwegian. English summary.]

559. Fullaway, S. V., Jr., Johnson, Herman M., and Hill, C. L.
1928. The air seasoning of western softwood lumber. U.S. Dep. Agr. Dep. Bull. 1425, 60 pp., illus.

560. Funk, A.
1965. A new parasite of spruce from British Columbia. Can. J. Bot. 43(1): 45-48 plus 6 photos.

Botryosphaeria piceae n. sp. is a parasite which causes perennial cankers of Sitka and Engelmann spruce in British Columbia. The affected branches may remain alive for many years. The fungus has been found only in the sexual state, producing ascospores chiefly in early spring. (From author's summary.)

561. Gale, B.
1947. Observations from the Isle of Man. Quart. J. Forest. 47(1): 16-19.

562. Gallagher, G.
1967. Spacing; thinning. Dep. Lands, Ireland, Forest Div. Forest Res. Rev. 1957/64: 66-75.

563. Gannett, Henry.
1902. The forests of Oregon. U. S. Geol. Surv. Prof. Pap. 4, 36 pp., illus.

564. Garman, E. H.
1957. The occurrence of spruce in the interior of British Columbia. Dep. Lands & Forests, Brit. Columbia Forest Serv. Tech. Pub. T-49, 31 pp., illus.

565. _____
1963. Pocket guide to the trees and shrubs of British Columbia. Ed. 3. Brit. Columbia Forest Serv. Pub. B-28, 137 pp., illus.

566. Gaskill, Alfred.
1913. Specific gravity and weight of the most important American woods. Forest. Quart. 11(4): 527-530.

Specific gravity of Sitka spruce is listed as 0.38, and weight is 24 pounds per cubic foot.

567. Gass, Charles R., Billings, Richard F., Stephens, Freeman R., and others.
1967. Soil management report for the Hollis area. USDA Forest Serv. Tongass National Forest, Alaska Region, 118 pp., illus.

Describes soils on a portion of Prince of Wales Island, Alaska. Western hemlock, Sitka spruce, western redcedar, and Alaska-cedar are the dominant trees in the forested zone, which extends from sea level to 1,500 feet. Average percentage of tree species in old-growth stands is tabulated by soil types.

568. Gerry, Eloise.
1942. Radial streak (red) and giant resin ducts in spruce. USDA Forest Serv. Forest Prod. Lab. Rep. 1391, 2 pp., illus.

569. Gibbs, R. Darnley.
1958. The Maule reaction, lignins, and the relationships between woody plants, pp. 269-312. *In* The physiology of forest trees, K. V. Thimann, W. B. Critchfield, and M. H. Zimmermann [eds.]. New York: The Ronald Press Co.

Sitka spruce showed a negative reaction to the test.

570. Gibson, Henry H.
1913. Sitka spruce. (*Picea sitchensis*.), pp. 133-135. *In* American forest trees, Maxwell Hu [ed.]. Chicago: Hardwood Record.

571. Gibson, W. N.
1951. Forestry in northern Ireland. Forestry 24(2): 152-158.

The progress made in forestry under the Ministry of Agriculture since 1921 is discussed, and conditions are compared with other parts of the United Kingdom. Sitka spruce is the main species being established and is ideally suited to the climate and soils over the greater part of northern Ireland. Some exceptionally fine stands have been produced on heavy clay loams, and growth rates and timber volumes probably compare favorably with any in the British Isles.

572. _____ and Brown, N. M.
1962. The history and future of forestry in the Middle Tweed. Forestry 35(2): 105-115 plus 2 photos.

573. Gifford, David.
1964. Studies on soil microarthropod populations in Scottish forests. *In* Report on forest research for the year ended March 1963. Great Brit. Forest. Comm., pp. 164-172. London: H. M. Stationery Office.

574. Gifford, E. R.
1959. Soil fauna research. *In* Report on forest research for the year ended March 1958. Great Brit. Forest. Comm., p. 116. London: H. M. Stationery Office.

Reports effects of establishing a Sitka spruce plantation on a population of soil-inhabiting mites.

575. Gilpin, W. J.
1965. The relation of crown width to D.B.H. and total height in open and forest grown Sitka spruce. 39 pp. (B.S. in Forest. thesis on file at Univ. Brit. Columbia.)

The relation of crown width to diameter at breast height and total height for open and forest grown Sitka spruce was examined. Three characteristics of open grown and forest grown trees were assessed by computer analysis. Multiple regression equations for estimation of crown width of open grown and forest grown trees were developed. Analysis of variance showed most of the variation in crown width could be accounted for by total height in both open and forest grown trees.

576. Gladman, R. J., and Greig, B. J. W.
1965. Principal butt rots of conifers. Great Brit. Forest. Comm. Booklet 13, 8 pp. plus 10 plates.

A forester's guide to the three most common and damaging decays of standing conifers in Great Britain, caused by *Fomes annosus*, *Armillaria mellea*, and *Polyporus schweinitzii*. Descriptions and illustrations show the gross characteristics of the fungi, and the rots they cause. (Some illustrations are in color.)

577. Glaser, H.
1955. Untersuchungen über die chemische Entrindung und ihre Anwendbarkeit in deutschen Wäldern. [Investigations on chemical barking and its applicability in German forests.] 87 pp., illus. Frankfurt-am-Main: J. D. Saverlander. [In German.]

Briefly surveys experimental work and experience gained in chemical debarking in countries outside Germany and includes a detailed description of the author's own tests in Germany over the period 1950-53. Sitka spruce peeled easily after chemical treatment.

578. Gockerell, E. C.
1966. Plantations on burned versus unburned areas. J. Forest. 64: 392-394.

Clearcut areas were examined for comparison of plantations of Sitka spruce and other conifers on burned and unburned units. Planted stocking is greater on burned areas, but there are fewer natural seedlings than on unburned areas. Average height of trees is greatest on unburned areas. Browsing by elk and deer is heaviest on burned areas.

579. Godman, R. M.
1949. What kind of trees make the best growth in southeast Alaska. USDA Forest Serv. Alaska Forest Res. Center Tech. Note 2, 1 p.

The average second-growth stand in southeast Alaska is composed of approximately equal proportions by volume of Sitka spruce and western hemlock. Remeasurement of four sample plots after 20 years showed that spruce increment is far greater than hemlock. Both species increase their rate of growth as they increase in diameter. Spruce outstrips hemlock in every vigor class.

580. _____
1951. Thinning second-growth hemlock-spruce for pulpwood. USDA Forest Serv. Alaska Forest Res. Center Tech. Note 7, 1 p.

Reports on a test of two thinning methods: leaving 120 crop trees per acre, and leaving two-thirds of original basal area.

581. _____
1952. A classification of the climax forests of southeastern Alaska. J. Forest. 50: 435-438.

Presents a classification scheme for the climax forests of southeast Alaska, a component of which is Sitka spruce. The average number of 16-foot logs to a 6-inch top diameter inside bark of trees in and above the average stand diameter was found to be the most practical single indicator of stand characteristics in the climax forests. Log height is roughly indicative of species composition. The stands are described in detail.

582. _____
1953. Seed dispersal in southeast Alaska. USDA Forest Serv. Alaska Forest Res. Center Tech. Note 16, 2 pp.

A bumper cone crop in 1951 produced 91 pounds of seed per acre in a western hemlock-Sitka spruce stand in the Juneau area of the Tongass National Forest. Seed fall by month is tabulated.

583. _____
1953. Moss retards regeneration in southeast Alaska. USDA Forest Serv. Alaska Forest Res. Center Tech. Note 18, 1 p.

584. _____
1953. Seasonal distribution of leader growth. USDA Forest Serv. Alaska Forest Res. Center Tech. Note 19, 2 pp.

585. _____
1953. Seasonal distribution of radial growth. USDA Forest Serv. Alaska Forest Res. Center Tech. Note 20, 1 p.

Radial growth at breast height began about May 15 in the Ketchikan area of the Tongass National Forest. For old-growth Sitka spruce, 50 percent of the increment was complete in 7-1/2 weeks, and appeared to terminate at 17 weeks. For second-growth spruce, 90 percent of the increment was complete in 11-1/2 weeks and growth was essentially complete by the 14th week. Weekly periodic and cumulative percentages of radial increment for old-growth and second-growth Sitka spruce, western hemlock, and western redcedar are given.

586. _____ and Gregory, R. A.
1953. Physical soil characteristics related to site quality in climax stands of southeast Alaska. USDA Forest Serv. Alaska Forest Res. Center Tech. Note 17, 1 p.

587. Godman, Richard M., and Gregory, Robert A.
1955. Seasonal distribution of radial and leader growth in the Sitka spruce-western hemlock forest of southeast Alaska. J. Forest. 53: 827-833.

Tables and graphs show weekly radial growth changes using Daubenmire's dendrometer for second-growth Sitka spruce, western hemlock, and western redcedar at Juneau and Hollis. Leader growth is included and the growing seasons are divided into the number and percent of days in which the growth occurs.

588. Godske, C. L.
1962. Investigations carried through at the station of forest meteorology at OS. III. On the relationship between air temperature and leading shoot increment for different coniferous trees. Arbok Univ. Bergen Mat., Natur. Ser. 15, 1961: 34.

589. Godwin, G. E.
1956. The Society's visit to Denmark. Forestry 29(2): 137-146.

Briefly describes forests and forest practices in Denmark. Several Sitka spruce stands were seen during the tour.

590. _____
1956. A major threat to Sitka spruce? Quart. J. Forest. 50(2): 119-123.

Dendroctonus (*hylesinus*) *micans* has spread alarmingly in Sitka spruce in Denmark since 1947 and killed whole plantations. It is as yet unknown in Great Britain, but its nearness gives some grounds for apprehension. (Author's summary.)

591. Gøhrn, V.
1962. Fortegnelse over nogle egnede importområder for skovfrø til anvendelse I Dansk kovbrug. [List of some suitable areas from which to import seeds for use in Danish forestry.] Dansk Skovforenings Tidsskr. 47(9): 401-427. [In Danish.]

592. _____, Petersen, B. Beier, and Henriksen, H. A.
1954. *Dendroctonus micans* angriffe und ihr verhaltnis zum durchforstungsgrad bekampfungsversuche. [Attacks by *D. micans*

and their relationship to thinning grade.] Eleventh Congr. Int. Union. Forest. Res. Organ. Proc. (Rome) 1953, Sect. 24, no. 2/3, pp. 656-663. [In German.]

Research in a dune plantation of Sitka spruce in Denmark showed that *D. micans* spread most rapidly into moderately and heavily thinned areas. Laboratory tests suggested that lead arsenate might be used as a stomach poison, but results of field experiments were generally unsuccessful. The biology and development of the insect are discussed.

593. Goldthwait, Richard P.
1963. Dating the little ice age in Glacier Bay, Alaska. Int. Geol. Congr. Rep., 21st Sess., Norden, 1960. Part 27: 37-46.

594. Goodey, J. B.
1965. The relationships between the nematode *Hopolaimus uniformis* and Sitka spruce. *In* Experiments on nutrition problems in forest nurseries, Blanche Benzian [ed.]. Great Brit. Forest. Comm. Bull. 37, 1: 210-211.

Results offer circumstantial evidence of possible damage to Sitka spruce nursery seedlings by parasite eelworms, particularly *H. uniformis*.

595. Gould, C. W.
1920. Commercial woods of the Pacific coast. Timberman 21: 34-39.

Includes information on annual wood production, estimated stands, uses, properties, and physical characteristics of several Pacific coast species including Sitka spruce.

596. Graham, K.
1951. The Sitka spruce weevil. Div. Forest. Biol. Dep. Agr. Can., Bi-mon. Progr. Rep. 7(5): 3-4.

597. Graham, R. D.
1956. The preservative treatment of eight Oregon conifers by pressure processes. Amer. Wood Preserv. Ass. Proc. 52: 117-138.

Air-dried crosstie sections of eight conifers, including Sitka spruce, were incised and pressure treated with a creosote-petroleum solution, using the full-cell, Lowry, and Rueping processes. Recommendations for treating each species are made. (From author's summary.)

598. Graham, Robert D.
1954. The air seasoning and preservative treatment of crossties from eight Oregon conifers. Amer. Wood Preserv. Ass. Proc. 50: 175-184.

Treatment with a coal-tar creosote-petroleum solution resulted in part solid black and part ringed penetration into Sitka spruce crossties for a total depth averaging 0.84 inch. There appeared to be no difference in treatability of heartwood and sapwood.

599. _____ and Miller, Donald J.
1964. Service life of treated and untreated fence posts. Oreg. State Univ. Forest Res. Lab., 24 pp.

Untreated Sitka spruce posts lasted for 6 years.

600. Graham, Samuel Alexander.
1952. Forest entomology. Ed. 3, 351 pp., illus. New York, Toronto, etc.: McGraw-Hill Book Co.

601. Grant, Donald.
1915. Classification of moorland at Fersit for purposes of planting. Roy. Scot. Arboricult. Soc. Trans. 29: 73-76 plus 1 plate.

602. Grant, John A., and Grant, Carol L.
1943. Trees and shrubs for Pacific Northwest gardens. 335 pp., illus. Seattle: Frank McCaffrey, Dogwood Press.

603. Graves, H. S.
1916. The forests of Alaska. Timberman 17(6): 33-37, illus.

604. Graves, Henry S.
1916. The forests of Alaska. Amer. Forest. 22(1): 24-37, illus.

605. Gray, H. R.
1956. The form and taper of forest-tree stems. Imp. Inst., Oxford Univ. Inst. Pap. 32, 79 pp.

Discusses sectional area-to-height relationship for the main stem of various forest-grown trees including Sitka spruce.

606. Great Britain Forest Products Research Board (London).
1951. Wood-water relationships. Great Brit. Forest Prod. Res. Board Rep. 1950: 12-13.

Measurements of the relative-humidity: moisture-content isotherms of Sitka spruce are shown in graphs, where absorption and desorption curves correspond to moisture content from dryness to 32.5 percent and back again.

607. _____
1951. The bending of tropical timbers. Great Brit. Forest Prod. Res. Board Rep. 1950: 22.

608. _____
1952. Electrical properties of wood. Great Brit. Forest Prod. Res. Board Rep. 1951: 51-53.

Describes a study of the effect of moisture content, grain direction and frequency on dielectric constant and loss tangent for Sitka spruce and several other woods.

609. _____
1952. Research on pruning. Great Brit. Forest Prod. Res. Board Rep. 1951: 55-56.

Some 2,900 pruned knots in British-grown Sitka and Norway spruce logs were examined from 76 trees and 29 localities. Measurements of over 1,200 of these knots have shown an average radial healing thickness of just under 0.5 inch of wood. Dissection showed no obviously diseased knots or wood, but symptoms were found in the bark similar to those associated with attack by *Stereum sanguinolentum* or other fungi: It is recommended that green pruning of spruce be avoided in Britain.

610. _____
1953. Seasoning in superheated steam. Great Brit. Forest Prod. Res. Board Rep. 1952: 12-13.

611. _____
1953. The structural use of timber. Great Brit. Forest Prod. Res. Board Rep. 1952: 16-17.

612. _____
1953. Determination of arsenic in wood and foliage. Great Brit. Forest Prod. Res. Board Rep. 1952: 46-47.

Results of analyses, after the removal of the organic matter by digesting the samples with an acid mixture, showed very little arsenic present in needles and wood of Sitka spruce subjected to two different treatments with arsenic applied to standing trees to facilitate bark removal.

613. _____
1953. Diffusion of water vapour through wood. Great Brit. Forest Prod. Res. Board Rep. 1952: 48-49.

Compares grade and strength of Sitka spruce from Scotland and from Kent.

614. _____
1954. Softwood mannan. Great Brit. Forest Prod. Res. Board Rep. 1953: 43.

A polysaccharide containing mannose and glucose units only has been isolated from Sitka spruce.

615. _____
1958. Effect of gamma rays on the hygroscopicity of wood. Great Brit. Forest Prod. Res. Board Rep. 1957: 46.

Sitka spruce specimens were exposed to gamma rays from Co^{60} at dosage levels of 1, 10, and 100 million radiation, and the equilibrium moisture content curves were then determined. Very heavy doses of radiation are needed to affect hygroscopicity (and possibly other physical properties), and the effect is negligible below 10 million radiation.

616. _____
1959. Wood bending: solid bending. Dir. Great Brit. Forest Prod. Res. Board Rep. 1958: 10.

Experiments to determine the bending properties of nine British-grown softwoods, including Sitka spruce, and ash indicated that they were intrinsically superior to many tropical hardwoods tested, but their gross properties and commercial values were adversely affected by knots.

617. _____
1960. Home-grown timber investigations. Dir. Great Brit. Forest Prod. Res. Board Rep. 1959: 5.

Mentions a special instrument designed for measuring the inclination of the grain in cross-sectional disks. This will be used in a study of variations in anatomical structure of Sitka spruce throughout the United Kingdom.

618. _____ 1961. *Ambrosia* (pinhole borer) and *Lymexylid* beetles. Damage in coniferous forests, Argyllshire. Dir. Great Brit. Forest Prod. Res. Rep. 1960: 30-31.

619. _____ 1961. Effect of specimen size on swelling. Dir. Great Brit. Forest Prod. Res. Rep. 1960: 42-43.

620. _____ 1962. Common furniture beetle (*Anobium punctatum*): biology, habits, and nutrition. Dir. Great Brit. Forest Prod. Res. Rep. 1961: 21.

A decrease in nutritional suitability from the bark toward the center in British-grown Sitka spruce was demonstrated by the insertion of larvae into sample blocks and a study of their development.

621. _____ 1962. Prevention and control of infestation. Ambrosia beetles. Dir. Great Brit. Forest Prod. Res. Rep. 1961: 24.

622. _____ 1962. Effect of pre-compression on strength. Dir. Great Brit. Forest Prod. Res. Rep. 1961: 31.

623. _____ 1964. Home-grown timber investigations: compression wood in Sitka spruce. Dir. Great Brit. Forest Prod. Res. Rep. 1963: 9-10.

624. _____ 1964. Special apparatus and techniques. Betaray method of density determination. Dir. Great Brit. Forest Prod. Res. Rep. 1963: 10.

Reports on continued work using the $C^{14}B$-particle technique to examine the density variation in Sitka spruce early wood with a view to selecting trees of above-average density. Preliminary results suggest that early wood density is not necessarily related to the rate of diameter growth and that some fast-growing stems may have early wood of adequate quality.

625. _____ 1964. Home-grown investigations. Wind damage in Sitka spruce. Dir. Great Brit. Forest Prod. Res. Board Rep. 1963: 10.

The bulges on one side of the stem, found in 30-year Sitka spruce that had broken off at 8- to 10-foot height, consisted of fast-grown compression wood overlaying a natural compression failure and associated ring shake apparently caused by bending in gales 2 years before.

626. _____ 1964. Timber mechanics. Quality and properties of home-grown timbers. Dir. Great Brit. Forest Prod. Res. Board Rep. 1963: 34-35.

Gives results of strength tests on green Norway and Sitka spruce.

627. _____
1966. Pulping of home-grown timbers. Great Brit. Forest Prod. Res. Board Rep. 1965: 18-19.

628. Great Britain Forest Products Research Laboratory (Princes Risborough).
1934. Preliminary note on the timber of home-grown Sitka Spruce (*Picea sitchensis* Carr). Forestry 8: 126-130, illus.

629. _____
1941. Grading softwoods for strength; stress-grades for beams. Great Brit. Forest Prod. Res. Lab. Leafl. 19, 7 pp., illus.

630. _____
1945. A handbook of Empire timbers. Rev., 142 pp. London: H. M. Stationery Office.

631. _____
1953. Trials of timber for plywood manufacture. Small-scale tests on: consignment 750, Scots pine; consignment 763, Sitka spruce. Great Brit. Forest Prod. Res. Lab. Progr. Rep. 21, 11 pp.

Gives data on processing trials, gluing properties, and veneer quality.

632. _____
1953. Properties of thinnings of home-grown Sitka spruce (*Picea sitchensis*). Great Brit. Forest Prod. Res. Lab. Progr. Rep. 1--Consignment 761, 12 pp. plus 9 figs.

Gives data on the following: rate of growth as shown by ring width; density; wood structure; conversion and quality of converted timber; grading; strength properties; seasoning properties and suitable schedules; durability and preservative treatment; and working properties. The timber proved to be fast-grown, with low specific gravity. The soft early wood, broad in comparison with the late wood, tears when sawn or worked with cutting tools, giving a poor finish. The timber is unsuitable for joinery. There was no appreciable collapse in seasoning, but pressure during preservative treatment caused collapse.

633. _____
1953. Properties of thinning of home-grown Sitka spruce (*Picea sitchensis*). Great Brit. Forest Prod. Res. Lab. Progr. Rep. 2--Consignment 763, 15 pp., illus.

The 49-year-old wood was from Gravetye Forest, Sussex. It was fast grown for the first 25 years, and averaged 10 or more rings per inch in the outer half. The report compares wood properties with that grown under different conditions elsewhere. The soft early wood tore when sawn or worked with a cutting tool but was more satisfactory than that from Inverliever. There was a large percent of grade II material and 1.4 percent of grade I. There was no appreciable collapse in seasoning, but collapse occurred during preservative treatment under pressure. The parcel was superior to that from Inverliever except for larger knots.

634. _____
1956. Combined report on the properties of thinnings of home-grown Sitka spruce (*Picea sitchensis*). Great Brit. Forest Prod. Res. Lab., 11 pp. plus 8 figs.

Describes wood structure, conversion, grading, and strength tests of thinnings from several plantations. In general, the wood was grown too fast for many uses.

635. _____
1957. Properties of thinnings of home-grown Sitka spruce (*Picea sitchensis*). Great Brit. Forest Prod. Res. Lab. Progr. Rep. 7--Consignment 879, 55 pp. plus 1 fig.

This consignment is considered separately because the wood is from a plantation seriously underthinned and growth rate was slow. Similar in specific gravity to faster grown timber, it showed higher values in equivalent fiber stress at maximum load, modulus of elasticity and compression parallel to the grain, a considerably lower value for hardness, and a slightly lower one for impact bending strength. Differences in growth rate made no appreciable difference in wood quality.

636. _____
1957. A handbook of softwoods. Dep. Sci., Ind. Res., 73 pp. London: H. M. Stationery Office.

Describes Sitka spruce trees, wood seasoning, and uses, in Canada and Great Britain.

637. _____
1958. Report on the properties of four different provenance consignments of Sitka spruce. Great Brit. Forest Prod. Res. Lab., 20 pp., illus.

Five trees, 30 years old, grown in Radnorshire were tested from each of four provenances: (1) Queen Charlotte Islands, (2) Mt. Olympus, Wash., (3) Siuslaw, Oreg., and (4) Siskiyou, Calif. Timber from (1) had the highest density and highest quality; differences in density between trees from the other three sources were not significant. (3) was less dense than (2) or (4). Trees from (3) were most subject to drought-crack but there was little difference between provenances in seasoning collapse. It is concluded that seed from northern provenances, especially that from (1), is preferable in timber quality.

638. _____
1967. Home-grown timbers - Sitka and Norway spruce. Great Brit. Forest Prod. Res. Board Rep. 1967: 5-6.

639. Great Britain Forestry Commission.
1930. Forestry commission yield tables for Scots pine and other conifers. 24 pp. London: H. M. Stationery Office.

Contains yield tables and height curves for Scots pine, European and Japanese larch, Norway and Sitka spruce, and Douglas-fir.

640. _____
1937. Spring frosts. Great Brit. Forest. Comm. Bull. 18, 131 pp., illus.

641. _____
1946. The thinning of plantations. Great Brit. Forest. Comm. Forest Oper. Ser. 1, 40 pp.

642. _____
1948. Broom as nurse to Sitka spruce. *In* Report on forest research for the year ended March 1947. Great Brit. Forest. Comm., p. 38. London: H. M. Stationery Office.

Reports striking results of using broom, *Cytisus scoparius*, on difficult moorland sites. Trees with broom nurses were growing well and fast, whereas those without remained in check or grew very slowly. A similar effect has been observed with Scots pine as a nurse for Sitka spruce, but this is slower in developing.

643. _____
1958. Forestry practice; a summary of methods of establishing forest nurseries and plantations with advice on other forestry questions for owners, agents, and foresters. Great Brit. Forest Res. Forest. Comm. Rep. 14, 93 pp.

644. _____
1967. Forty-seventh annual report of the Forestry Commissioners for the year ended Sept. 30, 1966. Great Brit. Forest. Comm., 75 pp. plus 8 plates.

Lists source and amount of Sitka spruce seed imported and number of nursery plants sold to the trade, forest year 1966. Earlier reports give similar information.

645. _____
1967. Vegetative propagation. *In* Report on forest research for the year ended March 1967. Great Brit. Forest. Comm., pp. 92-93. London: H. M. Stationery Office.

646. _____
1967. Normal yield tables for Sitka spruce, yield classes 80 and 60 and Norway spruce yield class 80. Suppl. 1 to Forest Management tables booklet 16. Great Brit. Forest. Comm. (London).

647. _____
1967. Fomes annosus: a fungus causing butt rot, root rot and death of conifers. Great Brit. Forest. Comm. Leafl. 5, 11 pp., illus.

An account of the life history, method of infection, damage, and control of the fungus.

648. Greeley, A. W.
1954. Alaska's acres at work...at last. Amer. Forests 60(10): 8-11, 52.

649. Greeley, W. B.
1920. Utilization of the forests of Alaska. Science N.S. 52(1341): 244.

650. _____
1921. Paper from American trees. Nat. Bus. 9(3): 39-40.

651. Green, George Rex.
1933. Trees of North America (exclusive of Mexico). Vol. 1, The conifers. 186 pp. Ann Arbor: Edward Bros., Inc.

652. Green, R. G., and Wood, R. F.
1957. Manuring of conifer seedlings directly planted in the forest. *In* Report on forest research for the year ended March 1956. Great Brit. Forest. Comm., pp. 132-139. London: H. M. Stationery Office.

653. Grefnes, Martin W.
1940-41. Alaska: pulp and paper possibilities. Timberman 42(12): 26, 28, 30, 32.

654. Gregory, P. H.
1963. Diseases of Sitka spruce seedlings. Rothamsted [England] Exp. Sta. Rep. 1962: 122-123.

655. Gregory, R. A.
1956. The effect of clearcutting and soil disturbance on temperatures near the soil surface in southeast Alaska. USDA Forest Serv. Alaska Forest Res. Center Sta. Pap. 7, 22 pp., illus.

Measurements were made in the forest and in a clearcut area, on plots with undisturbed moss cover or where the organic and mineral soils had been mixed. Air and soil temperatures were considerably increased during late spring and summer as a result of timber cutting. Open soils warmed earlier and cooled earlier and more rapidly than forested soils, and the difference in soil temperature was still appreciable at a depth of 24 inches. No injury to Sitka spruce seedlings from excessive heat or frost was observed. Moss-covered seedbeds proved less desirable than disturbed soils for germination and early survival, but once seedling roots were established in the moist layers below the moss, chance of survival seemed good. Germination in disturbed soils was earlier and more concentrated. Germination in the forest was late and prolonged, and seedlings were still in the succulent stage at the end of the growing season.

656. _____
1957. 1956 cone crop report for Alaska tree species. USDA Forest Serv. Alaska Forest Res. Center Tech. Note 35, 2 pp.

657. _____
1957. The accuracy of southeast Alaska site index estimates associated with variable numbers of height measurements. USDA Forest Serv. Alaska Forest Res. Center Tech. Note 38, 2 pp.

Estimates of site index tended to be higher when Sitka spruce was used for height measurements than when western hemlock was used. The difference increased as site index increased. Below site index 100 the difference was negligible.

658. _____
1957. A comparison between leader growth of western conifers in Alaska and Vancouver Island. USDA Forest Serv. Alaska Forest Res. Center Tech. Note 36, 2 pp.

The pattern of leader growth of western hemlock in southeast Alaska was similar to that recorded on Vancouver Island. Growth of Sitka spruce in Alaska stopped abruptly and earlier than that of western hemlock.

659. _____
1958. 1957 cone crop report for Alaska tree species. USDA Forest Serv. Alaska Forest Res. Center Tech. Note 41, 2 pp.

660. _____
1959. 1958 cone crop report for Alaska tree species. USDA Forest Serv. Alaska Forest Res. Center Tech. Note 44, 2 pp.

661. Gregory, Robert A.
1960. The development of forest soil organic layers in relation to time in southeast Alaska. USDA Forest Serv. Alaska Forest Res. Center Tech. Note 47, 3 pp.

The unincorporated organic layer was sampled on the Maybeso Experimental Forest, Prince of Wales Island, beneath a mature stand of western hemlock more than 300 years old, and under Sitka spruce stands about 230 and 125 years old. Average depth in inches and oven-dry weight in pounds per acre of the organic layer under stands of decreasing age were 6.20 and 235,418; 4.02 and 165,608; 1.59 and 47,916.

662. _____
1960. Estimating site index in sapling and pole stands in southeast Alaska. USDA Forest Serv. Alaska Forest Res. Center Tech. Note 48, 3 pp.

Presents a method for determining site index of young Sitka spruce by measurement of a six-node span.

663. Greguss, Pal.
1955. Identification of living gymnosperms on the basis of xylotomy. 263 pp., illus. Budapest: Akad. Kiado. [In German.]

Provides anatomical key and illustration of Sitka spruce wood.

664. Greig, B. J. W.
1962. *Fomes annosus* (Fr.) Cke, and other root-rotting fungi in conifers on ex-hardwood sites. Forestry 35(2): 164-182, illus.

The development of root and butt rot caused by *F. annosus* in Sitka spruce and other conifer crops planted on ex-hardwood ground is slower than that in second-rotation conifer plantations. This is apparently due to competition from other fungi, notably *Armillaria mellea*. Excavations on ex-hardwood sites showed that *F. annosus* was present in conifer thinning stumps, and that transference of infection occurred, causing butt rot. The investigations confirmed the need for stump protection of all conifer crops planted on ex-hardwood sites. Short accounts are given of the activity of

A. mellea and *Polyporus schweinitzii*, the other two important root-rotting fungi on these sites. (From author's summary.)

665. _____
1967. Honey fungus. (Rev.) Great Brit. Forest. Comm. Leafl. 6, 10 pp., illus.

The honey fungus *Armillaria mellea* (Vahl. ex. Fr.) is a root parasite occurring commonly in British woods. Sitka spruce is very susceptible and in some stands almost every tree is attacked. The discussion includes descriptions and life history, detection methods, relative susceptibility of tree species, conditions favoring infection, and method of prevention.

666. Griffin, D. M.
1957. Fungal damage to roots of Sitka spruce seedlings in forest nurseries. *In* Report on forest research for the year ended March 1956. Great Brit. Forest. Comm., pp. 86-87. London: H. M. Stationery Office.

Investigation of root systems of Sitka spruce and other conifer seedlings in nurseries, before and after partial sterilization, indicate that damage by fungal pathogens is insufficient to account for the poor growth of seedlings in such nurseries. It seems likely that much of the beneficial effect of partial sterilization is due to changes in the amount and nature of available nitrogen.

667. _____
1958. Influence of pH on the incidence of damping-off. Trans. Brit. Mycol. Soc. 41(4): 483-490, illus.

Using *Beta vulgaris*, *Brassica campestris*, *Picea sitchensis*, and *Pinus contorta* as hosts and *Pythium ultimum* as parasite over a wide range of soil reactions, it was ascertained that the main factor in changes in incidence of damping-off with change in soil pH is the vigor of the host as expressed in growth rate during the susceptible period. Sitka spruce showed a strong negative correlation between incidence of disease and growth rate.

668. _____
1965. A study of damping-off, root damage and related phenomena in coniferous seedlings in British forest nurseries. *In* Experiments on nutrition problems in forest nurseries, Blanche Benzian [ed.]. Great Brit. Forest. Comm. Bull. 37, 1: 212-227, illus.

Pythium spp., especially *P. ultimum*, are the main agents of damping-off of Sitka spruce and other conifers in British forest nurseries. The disease is largely limited to established nurseries with alkaline or near-neutral soil reaction and can be controlled by partial soil sterilization.

669. Griffith, B. G.
1940. Effect of indolebutyric acid, indoleacetic, and alpha napthaleneacetic acid on rooting of cuttings of Douglas-fir and Sitka spruce. J. Forest. 38: 496-501, illus.

Dormant cuttings of Douglas-fir and Sitka spruce were successfully rooted (80 and 100 percent, respectively) by treating with either

indoleacetic or indolebutyric acid. Indolebutyric acid was more effective for stimulating root development than either indoleacetic or x-naphthalene acetic acid. The most effective dosage for Sitka spruce was 25.0 parts per million for 24-hour treatment periods. Treatment during the period February 20 to March 30 gave best results for both species.

670. Griggs, R. F.
1914. Observations on the edge of the forest in the Kodiak region of Alaska. Torrey Bot. Club Bull. 41: 381-385.

The edge of the range of Sitka spruce is advancing westward rapidly across Kodiak Island.

671. _____
1936. The vegetation of the Katmai district. Ecology 17(3): 380-417, illus.

672. Griggs, Robert F.
1915. The effect of the eruption of Katmai on land vegetation. Amer. Geogr. Soc. Bull. 47: 193-203, illus.

673. _____
1918. The recovery of vegetation at Kodiak. Ohio J. Sci. 19(1): 1-57.

Describes recovery of plants, including Sitka spruce, after the eruption of Mt. Katmai.

674. _____
1922. The Valley of Ten Thousand Smokes. 341 pp., illus. Washington: Nat. Geogr. Soc.

675. _____
1934. Botany.--The problem of arctic vegetation. J. Wash. Acad. Sci. 24(4): 153-175.

676. _____
1934. The edge of the forest in Alaska and the reason for its position. Ecology 15(2): 80-96.

The advance of Sitka spruce across Kodiak Island, Alaska, is a long-term secular migration into new territory rather than a phase of a cyclic oscillation back and forth.

677. _____
1946. The timberlines of northern America and their interpretation. Ecology 27(4): 275-289, illus.

Describes Sitka spruce at the extreme western limit of its range in Alaska.

678. Gruineil, T. de.
1956. A note on peat afforestation with special reference to work carried out in Cloosh Valley, Connemara. Irish Forest. 13(2): 64-68.

On the basis of his own experience the author's recommendations for establishing a tree crop on Connemara peat are (1) drain intensively and prepare ground 6 months to a year before planting; (2) plant 1 + 1 *Picea sitchensis*, 1 + 1 broadleaved species; (3) apply ground mineral phosphate immediately after planting, at a rate of 3 ounces per plant for spruce and birch and 1 ounce for pine.

679. Guernsey, F. W.
1948. Wood waste as a source of pulp on the Pacific coast. Brit. Columbia Lumberman 23(9): 66, 107-108, 110-112.

680. Guiguet, C. J.
1953. An ecological study of Goose Island, British Columbia, with special reference to mammals and birds. Brit. Columbia Prov. Mus. Occas. Pap. 10, 78 pp., illus.

On Goose Island two plant associations are included in the general heading of coniferous forest; the typical coast climax association of western redcedar, western hemlock, and Sitka spruce, and an association that includes western redcedar and western hemlock with lodgepole pine, Alaska-cedar, and Pacific yew. The latter is a stunted forest forming an ecotone between spruce-hemlock and muskeg associations, and also predominates in rocky areas. Floral composition is described by the Aldous method.

681. Guillebaud, W. H.
1933. Experiments on the ages and types of nursery stock for planting out. Forestry 7: 73-84.

682. _____
1942. Investigation on the rate of drying of pit-props. Forestry 16: 13-31, illus.

683. _____ and Hummel, F. C.
1949. A note on the movement of tree classes. Forestry 23(1): 1-14, illus.

An investigation was made to find how tree classes (dominant, codominant, subdominant, and suppressed) are represented in pure, even-aged crops at different ages and under different thinning treatments, and to what extent individual trees tend to maintain or change their relative position in the canopy during the life of a stand. The species investigated included Sitka spruce.

684. Guinier, P.
1939. Utilization en papeterie du bois de trois coniferes Americains cultivés dans l'est de la France (Epicéa de Sitka, Sapin de Vancouver, Sapin de Douglas). [The utilization for papermaking of three American conifers planted in the east of France (*Picea sitchensis*, *Abies grandis*, and *Pseudotsuga douglasii*).] Du Comité des Forets Bull., pp. 748-761. [In French.]

685. Haack, Paul M.
1963. Volume tables for hemlock and Sitka spruce on the Chugach National Forest, Alaska. Northern Forest Exp. Sta. USDA Forest Serv. Res. Note NOR-4, 4 pp.

Volume tables are in board feet, Scribner Decimal C., and in cubic feet.

686. Haarløv, N., and Petersen, B. B.
1952. Temperaturmålinger i bark og ved af Sitkagran (*Picea sitchensis*) med saerlig henblik på temperaturen i gångsystemer af Hylesinus (*Dendroctonus*) micans. [Temperature measurements in bark and wood of *P. sitchensis* with particular reference to the temperature in tunnels of *D. micans*.] Forstl. Forsøgsv. Danmark 21(1): 43-91. [In Danish. English summary.]

687. Hachenberg, F.
1957. Misserfolge von Ausländeranbauten bei falscher Standortswahl. [Failures with exotics tried on unsuitable sites.] Holz-Zentralbl. 83(99): 1211-1212, illus. [In German.]

Sitka spruce planted in the Kastellaun district (Hunsruck) on badly aerated soils in the 1880's and 1890's showed heavy losses from frost and snow and made poor growth.

688. _____
1957. Bericht über diverse Ausländeranbauten im Forstamt Kastellaun/Hunsrück. [Report on various exotics in the Kastellaun Hunsruck forest district.] Allg. Forstzeitschrift 12(18/19): 234-236, illus. [In German.]

Describes the progress of Sitka spruce and other species planted between 1882 and 1890.

689. Haddock, Phillip G.
1961. Silvicultural views on the Canadian spruce forests. Forest. Chron. 37(4): 376-389.

690. _____
1961. Coniferous shade trees in suburban development. Thirty-seventh Nat. Shade Tree Conf. Proc. 1961: 147-159.

In rich well-watered soil, Sitka spruce might prove to be a successful shade tree but its use is not recommended because of insect pests, which are very troublesome, particularly under cultivation.

691. _____
1964. Intellectual prospecting report. Univ. Brit. Columbia Fac. Forest., 15 pp.

Describes a 5-week trip to Europe by the author in 1964. Sitka spruce plantations in Denmark, Norway, and Great Britain are described briefly. General impressions regarding silvicultural philosophy in Europe are given.

692. _____
1966. Information available for other western species having sufficient generality to be applied to Douglas-fir seed movement problems. Western Forest Genet. Ass. Proc. 1966: 8-22.

Contains a review of literature on provenance experience in Europe with several western conifers, including Sitka spruce.

693. Hagem, Oscar.
1931. Forsek med Vestamerikanske Traeslag. [Studies on western America tree species.] Medd. Vestlandet Forstl. Forsoekssta. 12, 4(2): 1-217, illus.

Describes Sitka spruce trials in Norway with provenances from Alaska, British Columbia, Washington, and California.

694. Halliday, W. E. D.
1937. A forest classification for Canada. Can. Forest Serv. Dep. Mines, Resources Bull. 89, 50 pp. plus map.

Sitka spruce is associated with western redcedar and western hemlock in the coast forest region, especially toward the northern portion of the region.

695. _____ and Brown, A. W. A.
1943. The distribution of some important forest trees in Canada. Ecology 24(3): 353-373.

Presents a series of maps showing the distribution of important forest trees, among them Sitka spruce.

696. Halvorsen, Birger.
1965. Kvalitetsegenskaper hos enkelte fremmede treslag. [Properties of wood of some exotic tree species.] Norsk Skogindustri 19(8): 310-314, illus. [In Finnish.]

697. Hanahoe, A. J.
1948. Extraction of conifer seed at Avondale, County Wicklow. Irish Forest. 5(1/2): 9-17.

An account of the design and operation of a kiln for extracting conifer seed, and comparative figures of the cost of imported and home-collected and extracted seed.

698. Hansbrough, J. R.
1934. Occurrence and parasitism of *Aleurodiscus amorphus* in North America. J. Forest. 32: 452-458, illus.

Sitka spruce is listed as a host for the fungus *Aleurodiscus amorphus*.

699. _____ and Englerth, G. H.
1944. The significance of the discolorations in aircraft lumber: Sitka spruce. U.S. Dep. Agr. Forest Pathol. Spec. Release 21, 14 pp.

700. Hansen, Carl.
1892. Pinetum danicum. Conifers collected and observed by Professor Carl Hansen, Mynstersvei 2, Copenhagen V. J. Roy. Hort. Soc. 14: 257-480.

701. Hansen, Henry P.
1938. Postglacial forest succession and climate in the Puget Sound region. Ecology 19(4): 528-542, illus.

702. _____
1940. Paleoecology of two peat bogs in southwestern British Columbia. Amer. J. Bot. 27: 144-149, illus.

703. _____
1941. Paleoecology of two peat deposits on the Oregon coast. Studies in Botany. Oregon State Univ. Monogr. 3, 31 pp., illus.

704. _____
1941. Further pollen studies of post Pleistocene bogs in the Puget lowlands of Washington. Torrey Bot. Club Bull. 68(3): 133-148, illus.

705. _____
1941. Paleoecology of a bog in the spruce-hemlock climax of the Olympic Peninsula. Amer. Midland Natur. 25: 290-297, illus.

706. _____
1943. A pollen study of two bogs on Orcas Island, of the San Juan Islands, Washington. Torrey Bot. Club Bull. 70(3): 236-243.

707. _____
1943. Paleoecology of two sand dune bogs on the southern Oregon coast. Amer. J. Bot. 30: 335-340.

708. _____
1947. Postglacial forest succession, climate, and chronology in the Pacific Northwest. Amer. Phil. Soc. Trans. New ser. vol. 37, part 1, 126 pp., illus.

Presents a reconstruction and analysis of postglacial vegetation by pollen analysis of sedimentary columns taken from peat bogs. Present day observations indicate that Sitka spruce succeeds lodgepole pine, and in turn is succeeded by western hemlock on dunes and other sandy areas. Spruce also precedes hemlock on mature peat bogs, indicating that it can thrive under less favorable conditions. Plant succession has been interrupted from time to time by accelerated sand movement, which permitted lodgepole pines periodically to regain predominance. There is little indication on the coastal strip of a climate drier and warmer than the present at any time during the postglacial period. The principal cause of change in forest composition has been the periodic shifting of sand, disrupting succession toward the climax vegetation.

709. _____
1950. Pollen analysis of three bogs on Vancouver Island. Can. J. Ecol. 38(2): 270-276, illus.

710. _____
1953. Postglacial forests in the Yukon Territory and Alaska. Amer. J. Sci. 251: 505-542, illus.

711. _____ and Allison, Ira S.
1942. Pollen study of a fossil peat deposit on the Oregon coast. Northwest Sci. 16(4): 86-92, illus.

712. _____ and Mackin, J. Hoover.
1949. A pre-Wisconsin forest succession in the Puget lowland, Washington. Amer. J. Sci. 247: 833-855, illus.

713. Hansen, J. E.
1957. Zu: Kann der Riesenbastkäfer (*Dendroctonus micans* Kug.) in Schleswig-Holstein erfolgreich bekämpft werden? [A note on: Can *D. micans* be successfully controlled in Schleswig-Holstein?] Forst- und Holzwirt 12(10): 167-168. [In German.]

The author considers nutrient deficiencies to be the chief cause of susceptibility to beetle attack in Sitka spruce, and reports on the application of nitrogen at the rate of 300 kilograms per hectare with the Ruhr-Stickstoff forest roller in a poor stand on sand with a thick raw-humus layer. Soil improvement was rapid, and all but two very heavily infested trees recovered.

714. Hanson, H. C.
1951. Characteristics of some grassland, marsh, and other plant communities in western Alaska. Ecol. Monogr. 21(4): 317-375.

The study included Sitka spruce and white spruce stands. Compared with grassland stands, the soil was shallower, rocks were more numerous on or near the surface, the soil showed more podzolization, and the root systems were shallower.

715. Hanson, H. S.
1951. Forest entomology. *In* Report on forest research for the year ended March 1950. Great Brit. Forest. Comm., pp. 83-91. London: H. M. Stationery Office.

The study of aphid and other insect pests of Sitka spruce was continued. Although formerly the green spruce aphis, *Neomyzaphis abietina*, was considered to be the only important insect enemy of Sitka spruce, 12 species of insect are now known to cause serious damage to current-year foliage. Where several pests occur in the same area, it seems probable that the combined effects of their attack on young crops may prevent satisfactory growth, whereas in their absence the trees might continue to make satisfactory recovery from the effects of *Neomyzaphis* attack.

716. _____
1952. Forest entomology. The green spruce aphis, *Neomyzaphis abietina* (Walker). *In* Report on forest research for the year ended March 1951. Great Brit. Forest. Comm., pp. 98-107. London: H. M. Stationery Office.

717. Hanson, P. D.
1960. Alaska--last frontier. Western Conserv. J. 16(4): 78-81, illus.

718. Hanzlik, E. J.
1925. A site classification scheme for the western Cascades forest region. Univ. Wash. Forest Club Quart. 4(1): 5-8.

719. Hanzlik, Edward John.
1928. Trees and forests of Western United States. 128 pp. Portland, Oreg.: Dunham Printing Co.

720. Hard, J. S.
1967. Identification of destructive Alaska forest insects. Inst. Northern Forest. USDA Forest Serv. Pacific Northwest Forest & Range Exp. Sta., 19 pp., illus.

721. Haring, Robert C., and Massie, Michael R. C.
1966. A survey of the Alaskan forest products industry. Univ. Alaska Res. Monogr. 8, 147 pp., illus.

722. Harlow, William M., and Harrar, Elwood S.
1958. Textbook of dendrology. Ed. 4, 561 pp., illus. New York: McGraw-Hill Book Co.

723. Harrar, E. S.
1957. Hough's encyclopaedia of American woods. 204 pp., illus. New York: Robert Speller & Sons.

Describes the tree and wood, including gross diagnostic features and minute anatomy, physical and mechanical properties, and uses.

724. Harris, A. S.
1960. 1959 cone crop report for Alaska tree species. USDA Forest Serv. Alaska Forest Res. Center Tech. Note 50, 2 pp.

725. _____
1962. Cone crops in coastal Alaska - 1960 and 1961. USDA Forest Serv. Alaska Forest Res. Center Tech. Note 53, 4 pp., illus.

726. _____
1963. Tree reproduction development on a mile-square clearcutting. (Abstr.) Thirteenth Annu. Alaska Sci. Conf. Proc. 1962: 87.

727. _____
1964. Sitka spruce--Alaska's new State tree. Amer. Forests 70(8): 32-35.

728. _____
1965. Aerial seeding Sitka spruce and western hemlock on a cutover area in southeast Alaska. Northern Forest Exp. Sta. USDA Forest Serv. Res. Note NOR-10, 6 pp., illus.

Aerial seeding combined with natural seedfall resulted in adequate initial stocking of cutover areas. Approximately 60 live seeds were needed to produce each seedling surviving at the end of the first growing season.

729. _____
1966. Effects of slash burning on conifer regeneration in southeast Alaska. Northern Forest Exp. Sta. USDA Forest Serv. Res. Note NOR-18, 6 pp., illus.

Slash burning after clearcutting of an old-growth western hemlock-Sitka spruce stand favored the establishment of Sitka spruce. Fewer seedlings were established on the burned than on the unburned test area, but distribution was more uniform on the burn. The higher percentage of spruce after slash burning stemmed from improved initial spruce establishment. Once

established, seedling survival was not affected by burning. Ground cover on burned and unburned areas are compared.

730. _____
1966. A test of pruning Sitka spruce in Alaska. Northern Forest Exp. Sta. USDA Forest Serv. Res. Note NOR-13, 3 pp., illus.

Describes a test of dead-limb pruning of 38-year-old trees. Clear wood production over smooth branch cuts began 5 to 12 years after pruning. Decay associated with pruning was not a problem.

731. _____
1967. Natural reforestation on a mile-square clearcut in southeast Alaska. Pacific Northwest Forest & Range Exp. Sta. USDA Forest Serv. Res. Pap. PNW-52, 16 pp., illus.

Natural reforestation on a 700-acre logging unit of the Maybeso Experimental Forest, Prince of Wales Island, Alaska, was studied during 9 years beginning with clearcutting of the old-growth western hemlock-Sitka spruce stand. Production and dissemination of seed and establishment, development, and species composition of tree reproduction are discussed.

732. Harris, Arland S.
1965. Subalpine fir on Harris ridge near Hollis, Prince of Wales Island, Alaska. Northwest Sci. 39(4): 123-128, illus.

Sitka spruce, mountain hemlock, and subalpine fir were found in scattered clumps at 3,000-foot elevation.

733. Hartmann, F. K., Querengasser, F., and Jahn, G.
1953. Unterlagen fur den Anbau westamerikanischer Nadelholzarten in Deutschland. [Basic data for the planting of western North American coniferous species in Germany.] Allg. Forst- und Jagdzeit. 125(1): 25-48. [In German.]

734. Hasan, S. M.
1953. Heart rot in trees with special reference to the development of butt rot in Sitka spruce. Pakistan J. Forest. 3(4): 178-185, illus.

Describes and discusses the results of an investigation of 25 trees, 40 years old, growing in Britain on a shallow soil with badly drained subsoil.

735. Hathway, D. E.
1960. Researches on the tannin content of the stembark of Sitka spruce and Douglas-fir. *In* Report on forest research for the year ended March 1959. Great Brit. Forest. Comm., pp. 115-116. London: H. M. Stationery Office.

Tannin content from bark of 27-year-old trees was not affected by the time harvested, but the red color of winter-harvested bark was more pronounced than from bark peeled during the growing season. After trees were cut, the amount of available tannin decreased with time. Therefore, bark should be peeled and dried within a month of felling.

736. _____
1961. Utilisation of tan barks: extraction of Sitka spruce bark. *In* Report on forest research for the year ended March 1960. Great Brit. Forest. Comm., pp. 107-108. London: H. M. Stationery Office.

Chemicals extracted from bark gave a usable product. N:N-dimethylformamide (IMF) and methanol both appear to be suitable agents for extracting spruce bark.

737. Hawkes, Carl.
1953. Planes release tree plantation. J. Forest. 51: 345-348, illus.

738. Hawley, Ralph C.
1936. Professional honesty as regards selective logging. J. Forest. 34: 136-138.

739. _____
1954. The practice of silviculture. Ed. 6, 525 pp., illus. New York: John Wiley & Sons.

740. Hayes, A. J.
1965. Studies on the decomposition of coniferous leaf litter. I. Physical and chemical changes. J. Soil Sci. 16(1): 121-140, illus.

Describes decomposition rate as measured by loss in dry weight, comparing *Picea*, *Pinus*, and *Abies* litter. Changes in nitrogen, carbon to nitrogen ratio, and extractable polyphenols are discussed.

741. _____
1965. Studies on the decomposition of coniferous leaf litter. II. Changes in external features and succession of microfungi. J. Soil Sci. 16(2): 242-257, illus.

Describes the colonization of litter by various fungal mycelia and accompanying changes in external appearance of litter.

742. _____
1965. Studies on the distribution of some phthiracarid mites (Acari: Oribatidae) in a coniferous forest soil. Pedobiologia, Jena 5(3): 252-261, illus.

743. Haygreen, J. G.
1963. Some reasons for variability in the shrinkage of green lumber. Univ. Minn. Sch. Forest. Forest Note 140, 2 pp.

The fiber saturation point of Sitka spruce was found to be 28 percent.

744. Hays, Henry E.
1960. Status of regeneration on areas logged on the South Tongass since 1954. (Abstr.) Eleventh Alaska Sci. Conf. Proc.: 146.

745. Hazard, John W.
1965. Timber resource statistics for southwest Washington. Pacific

Northwest Forest & Range Exp. Sta. USDA Forest Serv. Resource Bull. PNW-15, 32 pp.

746. _____ and Metcalf, Melvin E.
1964. Forest statistics for southwest Oregon. Pacific Northwest Forest & Range Exp. Sta. USDA Forest Serv. Resource Bull. PNW-8, 32 pp.

747. _____ and Metcalf, Melvin E.
1965. Forest statistics for west-central Oregon. Pacific Northwest Forest & Range Exp. Sta. USDA Forest Serv. Resource Bull. PNW-10, 35 pp.

748. Heaman, J. C.
1967. Plus tree register for hemlock and other species. Brit. Columbia Forest Serv. Forest Res. Rev. 1967: 42.

Sitka spruce plus tree records and all material available in the British Columbia Forest Service clone bank collected as part of experimental project 587 have been turned over to the Tree Improvement Board for the use of board members. Grafting techniques used for spruce were not satisfactory, and propagation by rooting appears preferable.

749. Hearmon, R. F. S.
1958. The influence of shear and rotatory inertia on the free flexural vibration of wooden beams. Brit. J. Appl. Phys. 9: 381-388, illus.

Describes experiments in which the frequencies of wooden beams are measured up to the 16th node, and a least-squares method is described for analyzing the results. Effects introduced by the anisotropic nature of wood are also investigated. (From author's summary.)

750. _____ and Barkas, W. W.
1941. The effect of grain direction on the Young's moduli and rigidity moduli of beech and Sitka spruce. Phys. Soc. Proc. 53: 674-680, illus.

751. _____ and Paton, J. M.
1958. The maximum moisture content of wood. Forestry 31: 53-62, illus.

The maximum moisture contents of 17 timbers including Sitka spruce were determined and compared with calculated values, assuming a density of 1.5 grams per cubic centimeter for the wood substance. The converse approach, in which the maximum moisture contents were used to determine basic densities, is also discussed.

752. Heath, G. W.
1966. The biology of forest soils. *In* Report on forest research for the year ended March 1965. Great Brit. Forest. Comm., pp. 103-106, illus. London: H. M. Stationery Office.

753. Hegnauer, R.
1962. Chemotaxonomie der Pflanzen. Eine Ubersicht uber die Verbreitiung und die systematische Bedeutung der Pflanzenstoffe. Band I. Thallophyten, Bryophyten, Pteridophyten und Gymnospermen. [Chemotaxonomy of plants. A survey of the distribution and

systematic significance of plant constituents. Thallophytes, Bryophytes, Pteridophytes and Gymnosperms.] Vol. I, 517 pp., illus. Basel and Stuttgart: Birkhauser Verlag. [In German.]

754. Heintzleman, B. F.
1923. The standing timber resources of Alaska. West Coast Lumberman 44(518): 102-103, 108, illus.

755. _____
1928. Pulp timber resources of southeastern Alaska. U.S. Dep. Agr. Misc. Pub. 41, 34 pp., illus.

Describes Sitka spruce in Alaska. The largest tree known is reported to be 14-1/2 feet in diameter at a point 6 feet above ground.

756. _____
1934. A plan for the management of brown bear in relation to other resources on Admiralty Island, Alaska. U.S. Dep. Agr. Misc. Pub. 195, 20 pp., illus.

The commercial forest stands on Admiralty Island are composed of about 80 percent western hemlock and 20 percent Sitka spruce. A few trees of Alaska-cedar are scattered through the commercial forests. Commercial forest land is estimated at 460,000 acres. Management of wildlife in relation to timber is discussed.

757. Heintzleman, B. Frank.
1949. Forest of Alaska. U.S. Dep. Agr. Yearbook 1949: 361-372, illus.

758. Heit, C. E.
1950. Physiology of germination. N.Y. State Agr. Exp. Sta. Rep. 1949: 42-43.

Seven species of spruce were studied. Sitka spruce did not germinate promptly and completely at temperatures of 20° C. or below. The smaller seeded spruce species were found to be sensitive to moisture during germination.

759. _____
1961. Laboratory germination and recommended testing methods for 16 spruce *Picea* species. Offic. Seed Anal. Ass. Proc. 51: 165-171, illus.

Summarizes research and experience on germination, and presents recommendations for 10 American and six exotic spruces, including Sitka spruce.

760. Heller, E.
1910. Partial list of plants, chiefly shrubs and trees. *In* Mammals of the 1908 Alexander Alaska Expedition. Univ. Calif. Zool. Pub. 5: 349-360, illus.

761. Helmers, A. E.
1960. Alaska forestry - a research frontier. J. Forest. 58: 465-471, illus.

Describes briefly research done and needed in Alaskan forests including silviculture, management, insects, disease, fire, products utilization, marketing, and wildlife research. Sitka spruce comprises about 30 percent of the timber volume in southeast Alaska.

762. Henman, D. W.
1961. Pruning of conifers by disbudding. *In* Report on forest research for the year ended March 1960. Great Brit. Forest. Comm., pp. 166-172. London: H. M. Stationery Office.

Hand disbudding as a means of producing knot-free timber has been unsuccessful with Sitka spruce.

763. _____
1963. Some effects of isolating selected plantation trees for the first sixteen to twenty-three years after planting. *In* Report on forest research for the year ended March 1962. Great Brit. Forest. Comm., pp. 145-156, illus. London: H. M. Stationery Office.

Describes the effect of drastic thinning on Sitka spruce, Norway spruce, and Douglas-fir. Within a plantation spaced 4-1/2 by 6 feet, some vigorous trees were completely freed from competition of surrounding trees. Some crop trees were pruned.

764. _____
1963. Pruning conifers for the production of quality timber. Great Brit. Forest. Comm. Bull. 35, 55 pp., illus.

Describes the results of experimental pruning of Sitka spruce and other conifers begun by the Forestry Commission in 1931. An appraisal is included of the aims of pruning, and the experimental results are used to make provisional recommendations for forest practice.

765. _____
1965. Effects of thinning and spacing. *In* Report on forest research for the year ended March 1964. Great Brit. Forest. Comm., p. 36. London: H. M. Stationery Office.

766. _____
1965. Growth fall-off in spruce crops. *In* Report on forest research for the year ended March 1964. Great Brit. Forest. Comm., pp. 38-39. London: H. M. Stationery Office.

767. _____
1965. Some early responses to increased intensity of heathland cultivation. *In* Report on forest research for the year ended March 1964. Great Brit. Forest. Comm., pp. 158-165. London: H. M. Stationery Office.

768. _____
1966. Seed trapping: Sitka spruce. *In* Report on forest research for the year ended March 1965. Great Brit. Forest. Comm., p. 31. London: H. M. Stationery Office.

Seed fall in a 38-year-old Sitka spruce stand began before October and continued through March. Total seed production was 1-1/4 million viable seeds per acre, although 70 percent of the trees in the stand bore no cones.

769. Hennig, Rolf.
1954. Die tierischen und pflanzlichen Schädlinge unserer wichtigsten fremdländischen Holzarten. [Animal and plant pests of our most important exotic species.] Z. Pflanzenkrankh. 61(5): 255-269. [In German. English summary.]

Mainly a review of German literature. Sitka spruce is among the species discussed.

770. Henriksen, H. A.
1951. Et udhugningsforsog I Sitkagran. [A thinning experiment in Sitka spruce.] Forstl. Forsøgsv. Danmark 20(5): 403-418, illus. [In Danish.]

Thinning experiments were begun in 1935 on spruce planted on dunes between 1905 and 1912. Results for four thinning grades are tabulated, showing the number of stems, average height and diameter, basal area, and volume; the annual volume and basal area increment at 2-year intervals over 16 years; the 1951 volume per hectare by diameter classes; and average stem form in 1951. An attack by *Hylesinus micans* in 1949-51 appeared to be related to the degree of thinning--most severe in the heavily thinned plots and slight in the unthinned or lightly thinned plots.

771. _____
1955. Undersøgelser over Sitkagranens vaekst sundhed og stabilitet i Vilsbol og Nystrup plantager. [Growth, health, and stability of Sitka spruce in Vilsbol and Nystrup plantations.] Dansk Skovforenings Fŏudualg, pp. 33-40, illus. [In Danish.]

772. _____
1956. Sitka-Fichte und Douglasie in der dänischen Forstwirtschaft. [Sitka spruce and Douglas-fir in Danish forestry.] Allg. Forstzeitschrift 45/46: 581-583, illus. [In German.]

773. _____
1958. Sitkagranens vaest og sundhedstilstand i Danmark. [The increment and health of Sitka spruce in Denmark.] Forstl. Forsøgsv. Danmark 24(1): 371. [In Danish. English summary.]

774. _____
1961. A thinning experiment with Sitka spruce in Nystrup dune forest. Forstl. Forsøgsv. Danmark 27(2): 175-232.

775. _____ and Jorgensen, E.
1954. *Fomes annosus* attack in relation to grade of thinning. Eleventh IUFRO Congress Proc.(Rome) 1953, Part 2, Sect. 24, pp. 663-667.

776. _____ and Jørgensen, Erik.
1953. Rodfordaerangreb I relation til udhugningsgrad. [*Fomes annosus* attack in relation to grade of thinning.] Forstl. Forsøgsv. Danmark 21(2): 215-251. [In Danish. English summary.]

777. Henry, A.
1917. Large Sitka spruces in Scotland. Quart. J. Forest. 11: 65-66.

778. Henry, Joseph Kaye.
1915. Flora of southern British Columbia and Vancouver Island: with many references to Alaska and northern species. 363 pp. Toronto: W. J. Gage & Co.

779. Hergert, H. L., and Goldschmid, Otto.
1958. Biogenesis of heartwood and bark constitutents. J. Organ. Chem. 23(5): 700-704, illus.

780. Herman, Francis R.
1964. Epicormic branching of Sitka spruce. Pacific Northwest Forest & Range Exp. Sta. USDA Forest Serv. Res. Pap. PNW-18, 9 pp., illus.

Presents the effects of thinning and road right-of-way cutting on origin and development of epicormic branches on Sitka spruce. Light thinnings did not cause significant increases in growth of epicormic sprouts. Stems bordering right-of-way cuttings had an abundance of vigorous sprouts. Suggests that moderate to heavy thinning will stimulate epicormic branching, but such sprouting should have little influence upon quality of pulpwood and structural lumber. (Author's summary.)

781. Hesmer, H., and Gunther, K. H.
1962. Auswirkungen des Trockenjahres 1959 in den wäldern Nordrhein-Westfalens. [Effects of the drought year of 1959 in the forest of North Rhine-Westphalia.] Forstarchiv 33(6): 113-125, illus. [In German.]

782. Hetherington, J. C.
1964. Brush control in coastal British Columbia. Brit. Columbia Forest Serv. Res. Note 38, 56 pp., illus.

Sitka spruce has a shade tolerance almost equal to grand fir but is unlikely to survive for long under heavy shade. It has had limited success when planted under salmonberry and other brush species. Methods of brush control are described.

783. _____
1967. *Picea sitchensis*. Crown diameter: stem diameter relationships in managed stands of Sitka spruce. Commonwealth Forest. Rev. 46(4): 278-281 plus 1 graph, 2 tables.

Straight line regression equations for the prediction of crown diameter from stem diameter are developed for a range of yield classes. The amount of variation in crown diameter accounted for was not significantly increased by the inclusion of tree height in the regression equation for all the data combined. The results are briefly discussed in the light of previous work. (Author's summary.)

784. _____ and Page, G.
1965. Forest site evaluation with particular reference to soil and physiographic factors. Welsh Soils Discuss. Group Nat. Agr. Adv. Serv. Rep. (Aberystwyth) 6: 58-69.

785. Heusser, C. J.
1953. Radiocarbon dating of the thermal maximum in southeastern Alaska. Ecology 34: 637-640, illus.

786. _____
1954. Alpine fir at Taku Glacier, Alaska, with notes on its postglacial migration to the Territory. Torrey Bot. Club Bull. 81(1): 83-86, illus.

Isolated Sitka spruce occur at almost 4,000-foot elevation on nunataks in the Juneau Ice Field, 8 miles from timberline.

787. Heusser, Calvin J.
1952. Pollen profiles from southeastern Alaska. Ecol. Monogr. 22(4): 331-352, illus.

788. _____
1954. Nunatak flora of the Juneau Ice Field, Alaska. Torrey Bot. Club. Bull. 81(3): 236-250, illus.

Decumbent individuals of Sitka spruce were found on four widely separated nunataks at the 3,500-3,900-foot elevation.

789. _____
1954. Additional pollen profiles from southeastern Alaska. Amer. J. Sci. 252: 106-119, illus.

790. _____
1955. Pollen profiles from the Queen Charlotte Islands, British Columbia. Can. J. Bot. 33: 429-449, illus.

791. _____
1955. Pollen profiles from Prince William Sound and southeastern Kenai Peninsula, Alaska. Ecology 36(2): 185-202.

792. _____
1960. Late-Pleistocene environments of north Pacific North America. Amer. Geogr. Soc. Spec. Pub. 35, 308 pp., illus.

Describes the distribution, habitat, and plant associates of Sitka spruce throughout its range. Sitka spruce became luxuriant from southeastern Alaska to Oregon during the Late Postglacial. It was a Late-Postglacial migrant along the ocean coast of the Kenai Peninsula and on Afognak and Kodiak Islands.

793. _____
1964. Palynology of four bog sections from the western Olympic Peninsula, Washington. Ecology 45: 23-40, illus.

794. _____
1965. A Pleistocene phytogeographical sketch of the Pacific Northwest and Alaska, pp. 469-483, illus. *In* The quaternary of the United States. H. E. Wright, Jr., and David G. Frey [eds.]. Princeton, N. J.: Univ. Press.

Discusses the migrations of Sitka spruce and its associates from middle Wisconsin times to the present. Late-Glacial vegetation in the Pacific Northwest was mostly lodgepole pine park land, which along the moist coastal strip was succeeded by Sitka spruce and then Sitka spruce-western hemlock. Like the area south of glacier boundaries in Washington, unglaciated coastal refugia may have served as centers for plant invasion of deglaciated terrain. Unglaciated interior Alaska also was an extensive refugium for the major forest trees.

795. Higgins, Norman C.
1957. The equilibrium-moisture-content/relative-humidity relationships of selected native and foreign woods. Forest Prod. J. 7: 371-377, illus.

Data on equilibrium moisture content at relative humidity between 21 and 93 percent, on fiber saturation points, volumetric shrinkage, specific gravity, and hysteresis are presented and discussed for Sitka spruce and 11 other woods. Methods of measuring humidities over saturated salt solutions are described.

796. Hiley, W. E.
1931. Improvement of woodlands. 250 pp., illus. London: Country Life, Ltd.

797. _____
1959. Two-storied high forest. Forestry 32(2): 113-116.

Douglas-fir's and Sitka spruce's annual rings might become too broad if the treatment described were applied, except at a rather advanced age. Nevertheless, the system has certain other advantages and, to attain these, it may be useful even if the annual rings become broader than optimum.

798. _____ and Cunliffe, N.
1923. Further observations of the relation of the height growth of trees to meteorological conditions. Ann. Appl. Biol. 10(3/4): 442-452, illus.

799. Hinson, W. H.
1961. Forest soils, long-term studies of the nutrient relations of forest crops and sites. *In* Report on forest research for the year ended March 1960. Great Brit. Forest. Comm., pp. 52-53. London: H. M. Stationery Office.

Tests of Sitka spruce needles from different parts of the same tree showed that nutrient status and needle weight are little affected by the position of the needles on the trees. Therefore, it should be possible to sample material from lower branches instead of from the top whorl (the normal sampling source) when access to the latter is difficult.

800. Hiorth, G.
1956. Allverdens traer i norsk jord. [Trees of the world on Norwegian soil.] 245 pp. S. Bern. Hegland-Flekkefjord: Tryktog Bundet Hos. [In Norwegian.]

Contains short notes on 500 kinds of conifers including Sitka spruce, and 1,500 broad-leaved trees and bushes; includes instructions for their culture.

801. _____
1956. Litt om produksjon av Sitkagranplanter. [Production of Sitka spruce seedlings.] Arsskr. norske Skogplantesk 1955: 89-95. [In Norwegian.]

802. Hodges, John D.
1967. Patterns of photosynthesis under natural environmental conditions. Ecology 48(2): 234-242, illus.

Net photosynthesis in six conifers including Sitka spruce was studied under various natural environmental conditions. Changes in the pattern of photosynthesis on clear days, especially the midday decrease, are apparently primarily controlled by changes in leaf water potential. In noble fir and Scots pine, water potential probably acts mainly through its influence on stomatal movement. In grand fir, Douglas-fir, hemlock, and Sitka spruce, however, some other mechanism, probably mesophyll resistance to CO_2 diffusion, seems to play a more important role. Both mechanisms probably operate concurrently in all species. Daily variations in leaf water potential seem to occur primarily in response to changes in atmospheric moisture or, more precisely, vapor pressure gradient from leaf to atmosphere. Variation in carbohydrate content, through its influence on solute concentration, may also influence leaf water potential. (From author's abstract.)

803. Hodges, John Deavours.
1965. Photosynthesis in forest tree seedlings of the Pacific Northwest under natural environmental conditions. 177 pp., illus. (Ph. D. thesis, Univ. Wash.) Ann Arbor: Univ. Microfilms.

A more detailed report than the preceding and following references.

804. _____
1965. Photosynthesis in forest tree seedlings of the Pacific Northwest under natural environmental conditions. (Abstr.) (Ph.D. thesis, Univ. Wash.) Diss. Abstr. 26(5): 2402.

805. Hoekstra, P. E., Merkel, E. P., and Powers, H. R., Jr.
1961. Production of seeds of forest trees. U.S. Dep. Agr. Yearbook 1961: 227-232.

The seedworm *Laspeyresia youngana* can infest as much as 79 percent of the cones on white spruce and Sitka spruce in Alaska.

806. Hoffman, B. E.
1913. Alaska woods, their present and prospective uses. Forest. Quart. 11(2): 185-200.

807. Hoffman, Bruce E.
1912. Sitka spruce of Alaska. Soc. Amer. Forest. Proc. 7(2): 226-238.

Describes silvics, range, occurrence, tolerance, seed, diseases and defects, uses, production, and management of Sitka spruce in Alaska.

808. _____ and Wakeman, W. J.
1937. The pulpwood resources of the lower Columbia River area. *In* the pulp and paper industry of the Pacific Northwest. Part II. U.S. Corps of Engineers, 81 pp., illus.

809. Holmes, G. D.
1950. The treatment of seed. *In* Report on forest research for the year ended March 1949. Great Brit. Forest. Comm., pp. 34-35. London: H. M. Stationery Office.

Tetrazolium bromide was selected as the most suitable staining compound tested both for the clarity of embryo staining and for nontoxicity. A standard viability test procedure has been developed, and a classification of stained embryos on the basis of the area stained and density of staining has been developed. Experiments over two seasons, using Sitka and Norway spruce, Scots pine, and European larch as test species, gave no evidence to support the practice of soaking seed before sowing, with the exception of Sitka spruce which showed an increase in final germination after soaking for 6 days (44 percent germination compared with 26 percent for unsoaked seed). Acid soaking had little effect on germination, and the final effect of acid treatment at the end of the first season was detrimental.

810. _____
1952. Forest tree seed investigations. *In* Report on forest research for the year ended March 1951. Great Brit. Forest. Comm., pp. 13-15. London: H. M. Stationery Office.

Four years' work on seed pretreatment by soaking was concluded and indicated that, for the species tested (Sitka and Norway spruces, Japanese larch, and Scots pine), soaking gave too little response to be worthwhile.

811. _____
1953. Chemical killing of trees to facilitate bark removal. *In* Report on forest research for the year ended March 1952. Great Brit. Forest. Comm., pp. 42-43. London: H. M. Stationery Office.

812. _____
1960. Supplementary report of the Forest Seeds Committee. Referee testing of *Picea sitchensis* and *Pseudotsuga taxifolia*. Twelfth Int. Seed Testing Ass. Conv. Proc., pp. 685-704. Oslo, Copenhagen: Frederiksberg Bogtrykker.

813. _____ and Buszewicz, G.
1954. Forest tree seed investigations, germination methods. *In* Report on forest research for the year ended March 1953. Great Brit. Forest. Comm., pp. 14-15. London: H. M. Stationery Office.

814. _____ and Buszewicz, G.
1955. Forest tree seed investigations. *In* Report on forest research for the year ended March 1954. Great Brit. Forest. Comm., pp. 1-4. London: H. M. Stationery Office.

815. _____ and Buszewicz, G.
1955. Experiments with cold-wet pretreatment as a method of increasing the germination rate of seed of Douglas-fir, Sitka spruce, and

lodgepole pine. *In* Report on forest research for the year ended March 1954. Great Brit. Forest. Comm., pp. 84-91. London: H. M. Stationery Office.

Soaking Sitka spruce seed in water or on wet blotting paper for 21 days at 36° F. increased germination rate.

816. _____ and Buszewicz, G.
1959. Forest tree seed investigations. *In* Report on forest research for the year ended March 1958. Great Brit. Forest. Comm., pp. 17-20. London: H. M. Stationery Office.

Sitka spruce seed stored 4 years at 2° C. showed negligible loss in viability.

817. _____ and Buszewicz, G.
1960. Forest tree seed investigations. *In* Report on forest research for the year ended 1959. Great Brit. Forest. Comm., pp. 15-18. London: H. M. Stationery Office.

818. _____ and Cousins, D. A.
1960. Application of fertilizers to checked plantations. Forestry 33(1): 54-73, illus.

In April 1959, the first large-scale aerial fertilizer application was done in Britain following 8 years of study at Wilsey Down forest, Cornwall, and Halwill forest, Devon. The paper reviews site problems and experimental results at Wilsey Down, with an account of the large-scale fertilizer-spreading operations.

819. _____ and Faulkner, R.
1952. Experimental work in nurseries. *In* Report on forest research for the year ended March 1951. Great Brit. Forest. Comm., pp. 15-26. London: H. M. Stationery Office.

820. _____ and Faulkner, R.
1953. Experimental work in nurseries. *In* Report on forest research for the year ended March 1952. Great Brit. Forest. Comm., pp. 15-27. London: H. M. Stationery Office.

821. _____ and Faulkner, R.
1955. Experimental work in nurseries. *In* Report on forest research for the year ended March 1954. Great Brit. Forest. Comm., pp. 5-18. London: H. M. Stationery Office.

822. _____ and Ivens, G. W.
1952. Chemical control of weeds in forest nursery seedbeds. Great Brit. Forest. Comm. Forest Rec. 13, 31 pp., illus.

Describes experiments to evaluate chemicals for the control of annual weeds in first-year seedbeds of coniferous tree species including Sitka spruce.

823. Holms, John.
1967. Sitka spruce weevil in British Columbia. Can. Dep. Forest. &

Rural Develop. Forest Insect & Disease Surv., Forest Pest Leafl. June 1967, 3 pp. plus 9 figs.

824. Holmsgaard, E.
1955. Arringsanalyser af Danske skovtraeer. [Tree-ring analyses of Danish forest trees.] Forstl. Forsøgsv. Danmark 22(1): 1-246. [In Danish.]

825. Holmsgaard, Erik, and Kjaer, Arne.
1951. Undersøgelse over spiring I laboratorium og planteskole at 4 *Abies* - og 2 *Picea* - arter. [Research on germination in the laboratory and nursery of 4 *Abies* and 2 *Picea* species.] Dansk Skovforen. Tidsskr. 36(4): 203-226, illus. [In Danish.]

826. Holst, M. J.
1955. Breeding for weevil resistance in Norway spruce. Z. Forstgenetik 4(2): 33-37.

A promising approach to breeding weevil-resistant Norway spruce appears to be the hybridization of weevil-resistant white spruce with Norway spruce. Attempts at direct crosses have so far failed, but possibilities are now being explored for using Sitka spruce as a bridge for the transfer of genes for weevil-resistance from white to Norway spruce.

827. Holstener-Jorgensen, H.
1961. Undersøgelse af traearts- og aldersindflydelsen på grundvandstanden i skovtraebevoksninger på Bregentved. [The effect of various tree species and age of stand on the ground water level in stands at Bregentved.] Forstl. Forsøgsv Danmark 27(3): 233-480, illus. [In Danish. English summary.]

Measurements on water consumption by different stands suggest that for the same depth of rooting, consumption by beech and oak is similar and that by Norway and Sitka spruce considerably higher. The possibility of drainage on sites where the water table is high, especially in beech and spruce stands, is discussed.

828. Holubcik, Milan.
1960. Prispevok k otazke pestovania cudzokrajnych drevin v nasich porastoch. [Raising exotics in Czechoslovak stands.] Les. Cas. 6(1): 64-75, illus. [In Slovak.]

Discusses very briefly experience with 14 conifers including Sitka spruce.

829. Home, John Milne.
1945. Notes on growth of Sitka spruce. Scot. Forest. J. 59: 84-86.

Comparative data are given for two plantations of Sitka spruce in Argyll and Dumfriesshire. The first is 21 years old, planted with a spacing of 6 feet and heavily thinned; the second is 32 years old, planted with 4-foot spacing, and has been more lightly thinned.

830. Hopkins, David M.
1959. Some characteristics of the climate in forest and tundra regions in Alaska. Arctic 12(4): 214-220, illus.

831. Hopkinson, A. D.
1931. Notes on the Sitka spruce and other conifers on Queen Charlotte Islands. Forestry 5: 9-13.

A general description of the forests. Sitka spruce is the main commercial species and comprises 20 to 40 percent of the timber volume. Natural regeneration is abundant, rooting depth is variable depending on soil conditions, and little storm-wind damage is to be seen.

832. Horn, Stanley F.
1943. This fascinating lumber business. 328 pp., illus. New York: Bobbs-Merrill Co.

833. Howell, Thomas.
1903. A flora of Northwest America. Vol. I. Phanerogamae. 792 pp. Portland, Oreg.: Thomas Howell.

834. Hubert, Ernest E.
1931. An outline of forest pathology. 543 pp., illus. New York: John Wiley & Sons.

835. Hudson, Winifred M.
1960. The effect of initial bending on the strength of curved laminated timber beams. Wood 25(6): 234-236, illus.

836. _____
1961. The effect of precompression on the static and impact bending strength of wood. Wood 26(1): 18-20, illus.

Specimens of Douglas-fir, Sitka spruce, and noble fir were preloaded to induce compression stresses, and were then reversed and tested to destruction in static and impact bending. Results show that the reductions in strength in static bending were relatively small compared with those in strength under impact loading. Compression failures, which may not be significant under some conditions, must continue to be of critical importance for the selection of material subjected to other than static loads. (From author's summary.)

837. Hulley, Clarence C.
1953. Alaska 1741-1953. 406 pp., illus. Portland, Oreg.: Binfords and Mort.

Sitka spruce planted in 1804 by the Russians at Dutch Harbor, Alaska, have maintained themselves but have not propagated.

838. Hulten, E.
1937. Outline of the history of arctic and boreal biota during the Quaternary period; their evolution during and after the Glacial period as indicated by the equiformal progressive areas of present plant species. 168 pp., illus. Stockholm: Bokforlags Aktiebolaget Thule.

839. Hulten, Eric.
1941. Flora of Alaska and Yukon I. Bot. Mus., Lunds Univ. Arsskr., N. F., Avd. 2, 37(1): 1-127, illus.

840. _____
1960. Flora of the Aleutian Islands, and westernmost Alaska peninsula with notes on the flora of Commander Islands. Ed. 2, 376 pp. plus 42 pp. maps and appendix and 38 plates. New York: Hafner Publ. Co.

Contains notes on Sitka spruce planted at Unalaska.

841. Hummel, F. C., and Brett, I.
1954. A simple method of estimating volume increment in stands of young conifers. Eleventh IUFRO Congress Proc. (Rome) 1953, Part 2, Sect. 25, pp. 794-798.

842. _____ and Christie, J.
1953. Revised tables (yield) for conifers in Great Britain. Great Brit. Forest. Comm. Forest Rec. 24, 23 pp., illus.

Gives yield tables and site curves for Scots pine, Corsican pine, Norway spruce, Sitka spruce, Japanese larch, European larch, and Douglas-fir; a revision of Great Brit. Forest. Comm. Bull. 10.

843. Hunt, George M., and Garratt, George A.
1967. Wood preservation. Ed. 3, 433 pp., illus. New York, St. Louis, etc.: McGraw-Hill Book Co.

844. Hunt, John, and Wright, Ernest.
1957. Needle-cast of Sitka spruce in Oregon. (Abstr.) Plant Dis. Rep. 41(7): 650.

845. Hunt, K., and Dutton, G. G. S.
1957. Sitka spruce hemicelluloses. (Abstr.) Chem. Can. 9(4): 62.

The hemicellulose contained d-xylose, l-arabinose, d-glucose, and d-glactose, as well as uronic acid components. Further extraction of the solid residue gave a hemicellulose which, on hydrolysis, yielded only d-glucose and d-mannose.

846. Hunt, Kenneth.
1957. The hemicelluloses of Sitka spruce. 48 pp. (M.S. thesis on file at Univ. Brit. Columbia.)

847. Huntington, LeRoy W.
1923. Forest aspects of Alaska. Univ. Wash. Forest Club Quart. 1(4): 15-26, illus.

848. Hussey, N. W.
1952. A contribution to the bionomics of the green spruce aphid (*Neomyzaphis abietina* Walker). Scot. Forest. 6(4): 121-130, illus.

Reports studies on Sitka spruce in Midlothian.

849. Husson, R., and Stauder, F.
1955. Lutte chimique contre le scolytide de l'epicea *Dendroctonus micans* Kug. [Chemical control of D. micans.] Rev. Forest. Franc. 7(7): 534-538. [In French.]

850. Hustich, Ilmari.
1952. The boreal limits of conifers. Arctic 6(2): 149-162.

851. Hutchinson, Ian.
1958. Some aspects of logging in the coast forest of British Columbia. J. Empire Forest. Rev. 37(1): 66-84, illus.

852. Hutchison, O. Keith.
1967. Alaska's forest resource. Pacific Northwest Forest & Range Exp. Sta. USDA Forest Serv. Resource Bull. PNW-19, 74 pp., illus., plus map.

Net volume of Sitka spruce sawtimber on commercial forest land in Alaska is estimated to be 54,198 million board feet. Net volume of growing stock is estimated to be 8,928,394,000 cubic feet. Tables give breakdowns by size, age, ownership, and grade. Forest conditions are described.

853. Hutchison, Robert.
1878. On the *Abies menziesii*, and its value for planting in Scotland, with detailed statistics of its progress in the country. Highland Agr. Soc. Trans. Ser. IV, 10: 174-185.

854. Hvass, Jens.
1950. Skyggeheuse og persienner til daekning af frobede. [Permanent high lath shades and lath screens for seedbeds.] Dansk Skovforen. Tidsskr. 35(5): 266-270, illus. [In Danish.]

855. Imperial Forestry Institute.
1959. Root disease of spruce on heavy soil. Imp. Forest. Inst. Rep. (Oxford) 1958-59: 14.

Decline in vigor in a 20-year-old Sitka spruce plantation on heavy clay soil was attributed to poor aeration leading to unsatisfactory root development. Pythium spp. were isolated from the soil, and experiments in inoculation of water cultures indicated that these species can cause a chronic disease that results in death of the finer roots and debility of the trees.

856. Institute of Forest Products.
1957. Conversion factors for Pacific Northwest forest products. Wash. State Dep. Conserv., Seattle, 28 pp.

Average weight of green Sitka spruce logs is 6,463 pounds per thousand board feet, Scribner scale. Weight per thousand board feet (nominal size air-dry, 12-percent moisture content) is 2,330 pounds; green weight per cubic foot is 38 pounds; air-dry (12-percent moisture) is 28 pounds. Values for other western conifers and softwoods are given. Many other conversion values, independent of species, are given.

857. Isaac, L. A.
1940. "Water sprouts" on Sitka spruce. USDA Forest Serv. Pacific Northwest Forest & Range Exp. Sta. Res. Notes 31, pp. 6-7.

Examination of a 90-year-old stand showed that development of epicormic branches on Sitka spruce was clearly related to exposure of the trees to side light. Thrifty new limbs were found only on trees within 60 feet of

the timber's edge, and mostly on those within 30 feet. Limbs alive but not thrifty were found on trees within 90 feet, whereas trees without epicormic branch formation were largely beyond 90 feet of the timber's edge.

858. _____
1940. Life of seed in the forest floor. USDA Forest Serv. Pacific Northwest Forest & Range Exp. Sta. Res. Notes 31, p. 14.

Tests of seed storage in the duff showed that there was no germination after the first year for Sitka spruce.

859. _____ and Meagher, G. S.
1936. Natural reproduction on the Tillamook burn two years after the fire. USDA Forest Serv. Pacific Northwest Forest & Range Exp. Sta., 19 pp., illus.

Discusses natural regeneration of several tree species, including Sitka spruce, following the Tillamook burn.

860. Isaac, Leo A.
1933. Reforestation by broadcast seeding in the spruce-hemlock type. USDA Forest Serv. Pacific Northwest Forest & Range Exp. Sta. Res. Notes 11, p. 8.

861. _____
1939. Reforestation by broadcast seeding with small-seeded species. USDA Forest Serv. Pacific Northwest Forest & Range Exp. Sta. Res. Notes 27, p. 9 plus 2 figs.

A study showed that a satisfactory stand of Sitka spruce can be obtained by broadcast seeding at the rate of 1 or 2 pounds of seed per acre if seeding is done within 2 years after a slash burn. The minimum amount of seed necessary is not known.

862. _____
1940. Vegetative succession following logging in the Douglas-fir region with special reference to fire. J. Forest. 38: 716-721.

863. _____
1960. Leo A. Isaac on silviculture. Six papers presented School of Forestry 1959. 32 pp., illus. Corvallis: Oreg. State Coll.

Sitka spruce is slightly more tolerant than Douglas-fir but less tolerant than western hemlock or western redcedar. It is a more prolific seeder than Douglas-fir and has a small seed (225,000 per pound). Limb shedding is variable and may be a genetic characteristic. Adventitious buds develop on boles after partial cuts or heavy thinning.

864. Isenberg, Irving H.
1951. Pulpwoods of United States and Canada. Ed. 2, 187 pp., illus. Appleton, Wis.: Inst. Pap. Chem.

865. Istratova, O. T.
1961. O khranenii pyl'tsy nekotorykh khvoinykh porod i ee prorastanii. [Storage of pollen of some conifers, and its germination.] Glav. Bot Sada, Moskva Bjull., 43: 53-56. [In Russian.]

Experiments with pollen gathered on the Black Sea coast of Caucasia showed that pollen of Sitka spruce germinated best on 12-15 percent sucrose solution. When stored in desiccators, either at room temperatures of 16° to 27° C., or in a refrigerator at 3° to 4°, Sitka spruce pollen remained viable for 3 months and 6 months, respectively.

866. Jack, W. H.
1961. Comparison of actual production thinning yield plot, and yield table estimates. Forest. Northern Ireland 2(1): 6-15.

Yield, as determined from measurements of felled trees on two thinning plots, was compared with yield as estimated from Forestry Commission yield tables. The tables gave a reasonably good estimate regardless of thinning schedules. Thinning-plot data should be used with caution.

867. _____
1962. Assessing growth rates of a forest from thinning yield plots. Forest. Northern Ireland 3(1): 21-31.

868. _____
1964. The results of some trials using paraquat. Forest. Northern Ireland 5(1): 31-32.

869. _____
1964. Weedkilling in young forest plantations using paraquat. Seventh Brit. Weed Contr. Conf. Proc. 1: 263-266.

870. _____
1965. Experiments on tree growing on peat in northern Ireland. Forestry 38(1): 20-40, illus.

871. _____
1966. Variation in density of freshly felled Sitka spruce, and changes in density with time after felling. Agr. Res. Rec. (Belfast) 15(2): 51-66.

872. James, G. A.
1956. The rodent problem on cutover areas in southeast Alaska. USDA Forest Serv. Alaska Forest Res. Center Tech. Note 31, 2 pp.

Describes results of a rodent trapping study on timbered and cutover land in Sitka spruce-western hemlock type on Prince of Wales Island, southeast Alaska.

873. _____
1959. Seed production in a scrub stand. USDA Forest Serv. Alaska Forest Res. Center Tech. Note 43, 3 pp.

Reports a study in a scrub stand containing 73 percent western redcedar (by basal area), the remainder consisting of western hemlock and mountain hemlock with occasional Sitka spruce. Results showed a high seed production, especially for western redcedar. The total production by all species of 46 pounds per acre in a light-to-medium seed year compares with 91 pounds from a climax stand in a good year. Seedfall by species and date is tabulated.

874. James, George A., and Gregory, Robert A.
1959. Natural stocking of a mile-square clearcutting in southeast Alaska. USDA Forest Serv. Alaska Forest Res. Center Sta. Pap. 12, 9 pp., illus.

Describes seed dispersal and natural conifer regeneration on a 700-acre clearcutting. The stand harvested was old-growth timber consisting of 76 percent western hemlock, 20 percent Sitka spruce, and 2 percent each of western redcedar and Alaska-cedar. Although initial stocking was adequate, the authors favor continuing the present rule-of-thumb that no part of a cutting should be more than 20 chains from a seed source.

875. James, N. D. G.
1955. The foresters companion. 312 pp. Oxford: Basil Blackwell & Mott, Ltd.

876. Jayne, B. A.
1959. Indices of quality: vibrational properties of wood. Forest Prod. J. 9: 413-416.

Describes a method of nondestructive testing of wood based on electronic sensing of induced vibrations. Experiments with clean wood of Sitka spruce were encouraging enough to warrant detailed studies of other species.

877. _____
1960. Some mechanical properties of wood fibres in tension. Forest Prod. J. 10: 316-322, illus.

Describes and diagrams stress-strain properties of 10 wood species including Sitka spruce, based on tests of single wood fibers.

878. Jeffers, J. N. R.
1955. Relationship between the percentage of usable conifer seedlings and the mean height of seedlings as assessed at stocktaking. *In* Report on forest research for the year ended March 1954. Great Brit. Forest. Comm., pp. 101-106. London: H. M. Stationery Office.

879. _____
1959. Regression models of variation in specific gravity in four provenances of Sitka spruce. J. Inst. Wood Sci. 4, pp. 44-59, illus.

Describes statistical methods used to investigate the variation of nominal specific gravity in samples taken from four provenances of Sitka spruce.

880. _____
1966. Relationship between compressive strength, moisture content, rate of growth, and maximum bow in home-grown pitprops. Forestry 39(1): 100-114.

881. _____ and Howell, R. S.
1957. Use of a fractionally-replicated design in a pilot survey of moisture content and specific gravity of spruce and pine bark. *In* Report on forest research for the year ended March 1957. Great Brit. Forest. Comm., pp. 151-159. London: H. M. Stationery Office.

882. Jensen, Arne., Stephansen, Kari, and Løken, Asbjorn.
1967. Stratifisering av frø fra *Picea abies* (L.) Karst. og *Picea sitchensis* (Bong.) Carr. En undersokelse av kjemiske forandringer i lopet av stratifisering. [Stratification of seed of *Picea abies* and *P. sitchensis*: a study of chemical changes during stratification.] Medd. Vestlandets Forstl. Forsøkssta. 43: 169-187, illus. [In Norwegian. English summary.]

Germinative energy of all Sitka spruce samples tested increased following stratification. In two samples the germinative capacity also increased. The chemical changes during stratification differ from those during seed ripening.

883. _____, Stephansen, Kari, and Løken, Asbjorn.
1967. Seed ripening of Norwegian coniferous trees. II. Variation in the chemical content and germination of seeds of *Picea abies* (L.) Karst. and *Picea sitchensis* (Bong.) Carr. Medd. Vestlandets Forstl. Forsøkssta. 44: 189-222, illus. [In English. Norwegian summary.]

Discusses and shows in graphic form the changes in germinative properties and chemical composition, at weekly intervals, of seeds of *P. abies* (three trees) and *P. sitchensis* (one tree).

884. Jensen, C. F.
1952. Orkanen den 11 Februar 1952. [The hurricane of 11 February 1952.] Dansk Skovfor. Tidsskr. 37(5): 290-298, illus. [In Danish.]

Sound Norway and Sitka spruce were about as windfirm as *Abies alba*.

885. Jepson, Willis Linn.
1910. The silva of California. Calif. Univ. Mem. Vol. 2. 480 pp., illus. Berkeley: Univ. Press.

886. _____
1923. The trees of California. Ed. 2, 240 pp., illus. Berkeley: Ass. Stud. Store.

887. _____
1933. Phytogeography of the coniferae of western North America. Fifth Pacific Sci. Congr. Proc., pp. 3255-3264.

888. Jevtic, Jeremije.
1962. Uporedna ispitivanja prirasta i produkcije biomase omorike, smrče i Sitke u rasadnickim uslovima. [Comparative studies on the increment and biomass production of *Picea omorika*, *P. abies*, and *P. sitchensis* in nursery conditions.] Sumarstvo 15(3/4): 147-158. [In Serbian.]

At 3 and 5 years of age, Sitka spruce seedlings showed greatest height, biomass, and root-collar diameter. The root-shoot relationship was shown to depend on age and species as well as on nursery treatment.

889. Johnson, F. A.
1955. Volume tables for Pacific Northwest trees. (A compilation.) U.S. Dep. Agr. Handbook 92, 6 pp. plus 122 tables.

Gives volume tables (cubic feet and board feet) for 18 species of Pacific Northwest conifers, including Sitka spruce.

890. Johnson, Herman M.
1943. Recovery of aero quality lumber from Alaska spruce logs. Timberman 44(7): 56-57, 64.

An enterprise known as the Alaska Spruce Log Program was set up to produce aero quality logs. The first Davis raft was delivered at Anacortes, Wash., in January 1943. Quality of the Alaskan logs is described and compared with those from Oregon. Alaskan logs averaged 1 to 9 inches smaller in diameter, had 5 percent greater defect, and off-center heart was present in one-third of the logs. The off-center condition was seldom present in Oregon logs.

891. Johnson, Hugh, and Jorgenson, Harold T.
1963. The land resources of Alaska. 551 pp. New York: Univ. Publ.

892. Johnson, L. P. V.
1939. A descriptive list of natural and artificial interspecific hybrids in North American forest-tree genera. Can. J. Res. 17(12): 411-444.

Contains table showing interspecific crosses of *Picea sitchensis* Carr. with *P. canadensis* B.S.P., and *P. engelmanni* Engelm., with country, author, and date of report or of origin.

893. Johnson, Norman E.
1965. Distribution of Sitka spruce weevil eggs on leaders of open-grown Sitka spruce in southwest Washington. Weyerhaeuser Forest. Pap. 3, 11 pp., illus.

The Sitka spruce weevil (*Pissodes sitchensis* Hopk.) was found to start oviposition near the tip of the leader of Sitka spruce. As the season progressed, the weevil moved farther down the terminal, ovipositing with decreasing frequency until reaching the node. Most eggs were laid on the side of the terminal away from the afternoon sun. (From author's summary.)

894. _____
1965. A test of 12 insecticides for the control of the Sitka spruce weevil, *Pissodes sitchensis* Hopkins. J. Econ. Entomol. 58: 572-574.

Twelve insecticides are listed in increasing order of effectiveness, with respect to untreated control.

895. _____ and Zingg, John G.
1966. A test of several systemic insecticides for postoviposition control of the Sitka spruce weevil (*Pissodes sitchensis*). J. Econ. Entomol. 59: 765-766.

Oxydemetonmethyl, Bidrin, and probably Azodrin, would appear to be effective if applied in May. Concentration should be about 1 percent and the spruce leaders should be thoroughly wetted.

896. Johnson, R. P. A., and Gibbons, W. H.
1929. Properties of western hemlock and their relation to uses of the wood. U.S. Dep. Agr. Tech. Bull. 139, 62 pp., illus.

897. Johnston, D. D., and Pratt, G. H.
1962. The air-seasoning of Sitka spruce in Scotland. Scot. Forest. 16(3): 148-156, illus.

An investigation was made into the rates at which sawn Sitka spruce could be air-dried at Strachur, Argyllshire, where the annual rainfall averages about 90 inches and at Culloden, near Inverness, where it is only about 29 inches.

898. Johnston, D. R.
1954. Structure drawings to "specimen woods" sheet 40: Muputu, mjombo, Sitka spruce, Morabukea. Wood 19(10/12): 410.

899. _____ and Bradley, R. T.
1963. Forest management tables. Great Brit. Commonwealth Forest Rev. 42(3): 217-227.

Introduces and explains the new Forestry Commission management tables currently in preparation.

900. Joly, R.
1961. Les causes animales dans le jaunissement et la chute des aiguilles de l'épicéa de Sitka (*Picea sitchensis*) et d'autres épicéas. [The animal causes of yellowing and needle-cast of *P. sitchensis* and other spruces.] Rev. Forest. Franc. 13(3): 179-186, illus. [In French.]

901. Jones, George Neville.
1936. A botanical survey of the Olympic Peninsula, Washington. Univ. Wash. Biol. Pub. 5, 286 pp., illus.

902. _____
1938. The flowering plants and ferns of Mount Rainier. Univ. Wash. Biol. Pub. 7, 192 pp. plus 9 plates.

903. Jones, LeRoy.
1962. Recommendations for successful storage of tree seed. Tree Planters' Notes 55: 9-20.

Recommends conditions for Sitka spruce as follows: moisture content, 4 to 6 percent; highest acceptable temperature, 33° to 38° F. Storage below 32° F. is preferable.

904. Jones, Nard.
1954. Ketchikan's "catch"--the new pulp mill. Amer. Forests 60(10): 12, 13, 38.

905. Jørgensen, C. A., Lund, A., and Treschow, C.
1939. Undersøgelser over rodfordaerveren, *Fomes annosus* (Fr.) Cke. [Studies on the heart-rot fungus, *Fomes annosus* (Fr.) Cke.] K. Veterinaer Højskole Aarsskr., pp. 71-129. [In Danish. English summary.]

Outlines the regional distribution of the fungus in Denmark. Among the conifers grown in that country, Sitka spruce is the most susceptible to the fungus.

906. Jørgensen, Erik.
1955. Trametesangreb i laehegn. [*Fomes annosus* infection in shelterbelts.] Dansk Skovforen. Tidsskr. 40(6): 279-285, illus. [In Danish. English summary.]

Infection in shelterbelts at three forest research stations, containing *Sorbus* spp., thorn, beech, and Sitka spruce, separately or in mixture, probably originated from softwood fence posts attacked by the fungus.

907. Jørgensen, M. Blangstrup.
1955. Traeer på Grønland. [Trees in Greenland.] Horticultura (Copenhagen) 9(2): 25-30, illus. [In Danish.]

908. Joyce, P. M.
1953. Comparison in yields of Sitka and Norway spruce (in Ireland). Irish Forest. 10(2): 67-68.

Measurement of 1/10-acre plots of 30-year-old Sitka and Norway spruce showed that mean annual increment of Sitka spruce was 72 percent greater than that of Norway spruce. Forestry Commission yield tables are quoted for comparison with results in Great Britain.

909. Junack, Gartow.
1961. Alte und neue Kulturmethoden der Kiefer und ihrer Mischholze in wirtschaftlicher Prufung. [Old and new methods of planting and sowing pine and species mixed with it considered economically.] Forsttech. Inform. (Mainz) (4): 25-30, illus. [In German.]

Describes labor and costs associated with shovel planting of Sitka spruce and other conifers without preparatory soil treatment in semishade of partly destroyed stands. The method was economical and highly successful.

910. Juttner, Otto.
1954. 70 Jahre Heideaufforstung. [Seventy years of heath afforestation.] Veroffentlichungen Akad. Raumforschung Landesplanung (Raumforschung Landesplanung Abhandl.) Bremen-Horn No. 27, 191 pp., illus. [In German.]

Sitka spruce is one of the species sometimes used successfully for heath afforestation in the coastal heaths of Germany from the Danish to the Dutch frontier.

911. Kangur, R.
1954. Shrews as tree seed eaters in the Douglas-fir region. Oregon State Board Forest. Res. Note 17, 23 pp., illus.

The study showed that shrews (*Sorex* spp.), though classed as insectivores, were eating great quantities of Douglas-fir seed (50 to 100 percent of seed in acceptance spots), and much Sitka spruce seed (15 to 50 percent), a species which is usually considered safe from seed-eating rodents.

912. Karlberg, Sten.
1961. Development and yield of Douglas-fir (*Pseudotsuga taxifolia* (Poir.) Britt.) and Sitka spruce (*Picea sitchensis* (Bong.) Carr.) in southern Scandinavia and on the Pacific coast. Skr. K. Skogshogsk. 34, 141 pp.

Presents data and yield tables for the two species, drawn mainly from Danish material, and compares their growth in Scandinavia and on the Pacific coast of North America.

913. Kausch, von Schmeling, W.
1962. Dürreschäden 1959 in den Kulturen der sandstandorte Schleswig-Holsteins. [Drought damage in 1959 in plantations on sandy sites in Schleswig-Holstein.] Forstarchiv 33(10): 211-213. [In German.]

A survey of plantations, including Sitka spruce, showed that all planting methods that reduced weed competition aided survival. Plants that suffered from late frosts were particularly susceptible to drought damage.

914. Kay, James.
1920. Notes on Jack pines and Sitka spruce. Roy. Scot. Arboricult. Soc. Trans. 34: 149-155 plus 2 plates.

915. _____
1922. The geographical range of Sitka spruce, western larch, and Douglas-fir. Roy. Scot. Arboricult. Soc. Trans. 36(2): 197-201.

916. Keen, F. P.
1952. Insect enemies of western forests. U.S. Dep. Agr. Misc. Pub. 273, 280 pp., illus.

Includes descriptions of insects affecting Sitka spruce, their life histories, and importance to management.

917. _____
1958. Cone and seed insects of western forest trees. U.S. Dep. Agr. Tech. Bull. 1169, 168 pp., illus.

The bulletin is arranged under tree, general, and species headings, with keys to seed and cone insects for each genus; and under insect pests, arranged systematically, with notes on life history, damage, hosts, distribution, etc. There is also a brief section on control. A list of species isolated from Sitka spruce cones is included; none are considered serious threats.

918. Kellog, R. S.
1910. The forest of Alaska. USDA Forest Serv. Bull. 81, 24 pp., illus.

919. Kelsey, Harlan P., and Dayton, William A.
1942. Standardized plant names. Ed. 2, 675 pp. Harrisburg, Pa.: J. Horace McFarland Co.

920. Kelso, William Cheatom.
1963. The effect of air blockage upon the permeability of wood to liquids. (Ph.D. thesis, Univ. Minn., 1962.) Diss. Abstr. 24(1): 12.

921. Kelso, W. C., Jr., Gertjejansen, R. O., and Hossfeld, R. L.
1963. The effect of air blockage upon the permeability of wood to liquids. Univ. Minn. Agr. Exp. Sta. Tech. Bull. 242, 40 pp., illus.

Experiments were made, using specimens of air-seasoned Sitka spruce heartwood and distilled water, to determine the conditions required for air to evolve from a liquid as it is forced through wood, thus causing bubbles and blocking the flow.

922. Kennedy, Elma I.
1965. Strength and related properties of woods grown in Canada. Dep. Forest. Forest Prod. Res. Br. Pub. 1104, 51 pp.

923. Kenwood, L. G.
1961. The influence of site quality on the height growth of some coniferous seedlings. 40 pp. (B.S. in Forestry thesis, on file at Univ. Brit. Columbia.)

Describes an attempt to measure the influence of site quality on growth of several tree species including Sitka spruce. Ninety-nine percent of the variation in average seasonal height growth on plots was attributable to their site indices.

924. Kimmey, James W.
1953. Survey in Alaska for forest-tree diseases, including cull in Sitka spruce and western hemlock. Fourth Alaska Sci. Conf. Proc. 1953: 110-112.

925. _____
1956. Cull factors for Sitka spruce, western hemlock, and western redcedar in southeast Alaska. USDA Forest Serv. Alaska Forest Res. Center Sta. Pap. 6, 31 pp., illus.

Fungi attacking Sitka spruce are listed as *Fomes pini, Armillaria mellea, Fomes annosus, Merulius sp., Fomes nigrolimitatus, Fomes pinicola, Polyporus schweinitzii, Polyporous sulphureus, Trametes heteromorpha, Lentinus kauffmanii.* A method of estimating cull percent from surface indicators is given.

926. _____ and Stevenson, John A.
1957. A forest disease survey of Alaska. U.S. Dep. Agr. Res. Serv. Plant Dis. Rep. Suppl. 247: 87-98.

Lists 21 fungi collected on Sitka spruce. *Fomes pinicola* is the principal cause of heartrot in living Sitka spruce and causes most of the brown rot in western hemlock in Alaska. One of the principal means of entrance is through frost cracks in the bole of the trees. The prevalence of frost cracks increases in both spruce and hemlock toward the northern limit of their ranges.

927. Kindt, Svend.
1935. Sitkagran. [Sitka spruce.] Dansk Skovfor. Tidsskr. 10: 524-534, illus. [In Danish.]

928. _____
1956. En prøveflade i Sitkagran afsluttet. [Final results from a sample plot of Sitka spruce.] Dansk Skovfor. Tidsskr. 41(3): 147-149, illus. [In Danish.]

929. King, James E.
1958. Development of a stand of coniferous reproduction and interplanted Douglas-fir. Northwest Sci. 32(1): 1-8.

Stocking of an area with a sparse stand of young conifers, including Sitka spruce, was improved by interplanting with Douglas-fir, although animal damage and brush competition were serious obstacles to survival of planted trees. *Chermes cooleyii* had retarded or deformed 48 percent of the Sitka spruce in the natural stand.

930. Kinghorn, J. M.
1954. The influence of stand composition on the mortality of various conifers, caused by defoliation by the western hemlock looper on Vancouver Island, British Columbia. Forest. Chron. 30(4): 380-400.

In the first year after the collapse of the outbreak in 1946, tree mortality was light and only totally defoliated trees died. During the second and third years, mortality increased considerably, but by 1950 it had declined, surviving trees had recovered, and cumulative mortality up to 1950 was taken as the total suffered in the outbreak. Larger Sitka spruce trees suffered higher mortality for all defoliation classes than smaller trees, and mortality increased with percent of defoliation. Differences in mortality rates in crown, aspect, and altitudinal categories are explicable in terms of diameter or defoliation differences.

931. Kirk, Ruth.
1966. The Olympian rain forest. 86 pp., illus. Seattle: Univ. Wash. Press.

932. Klein, David R.
1965. Ecology of deer range in Alaska. Ecol. Monogr. 35(3): 259-284, illus.

In some areas on Coronation Island, new growth on spruce has been hedged by deer. This is most apparent adjacent to beaches at the heads of bays, although it also occurs where dwarfed spruce is available to deer at timberline. Spruce is rarely eaten by deer in southeast Alaska, and hedging of new growth has only been observed on small islands that have continued to support relatively high deer densities for many years.

933. Klein, J. A.
1951. Defect in the climax forests of southeast Alaska. USDA Forest Serv. Alaska Forest Res. Center Tech. Note 9, 1 p.

Sitka spruce is less defective on better sites. The largest trees on any site are the most defective. Percent cull due to visible defect is tabulated by species, diameter class, and site.

934. Kloft, W., and Ehrhardt, P.
1959. Untersuchungen über Saugtätigkeit und Schadwirkung der Sitkafichtenlaus *Liosomaphis abietina* (Walk.) (*Neomyzaphis abietina* Walk.). [Studies on the sucking activity and damage caused by *Neomyzaphis abietina*.] Phytopath. Z. 35(4): 401-410, illus. [In German. English summary.]

N. abietina was bred and studied on 5- to 6-year Sitka spruce under long-day conditions in the laboratory. Attack is through the stomata; the insect pierces the parenchyma and sucks the central phloem, producing honeydew. Seven amino acids were found in the saliva of adults. The mean time between the piercing of the needle and the appearance of chlorotic flecks was 5 to 6 days for larvae, 8 to 10 for adults. The uptake of P^{32} in these chlorotic spots was considerably below that of the healthy green parts of the needles. Respiration was increased and photosynthesis decreased in the damaged needles.

935. _____, Kunkel, H., and Ehrhardt, P.
1960. Beitrag zur Lachnidenfauna Mitteleuropas. [Notes on Central European lachnids.] Beitr. Entomol. 10(1/2): 161-168, illus. [In German. English summary.]

Includes a description of *Cinara pilicornis* on Sitka spruce with notes on its importance as a honeydew producer for bees and on ant trophobiosis.

936. _____, Ehrhardt, P., and Kunkel, H.
1961. Die Fichtenrohrenlaus *Elatobium abietinum* (Walk. 1849), ein endemisches Insekt der Rotfichte *Picea excelsa* in Europa. [*Neomyzaphis abietina* endemic on *P. abies* in Europe.] Waldhygiene 4(3/4): 121-125, illus. [In German.]

The aphid is endemic in Europe over the whole area of cultivation of Norway spruce, thought to be its natural host. Within the spruce's natural range, high densities (five to seven aphids per needle) have been found occasionally. Elsewhere, mass outbreaks have occurred only on exotics, particularly Sitka spruce, which is considered in danger from this pest over the whole area. In regions under Atlantic influence, mass outbreaks are further favored by anholocyclic hibernation.

937. Knudsen, H., and Gregersen, A.
1967. Forsøg med renholdelse og gødskning af nyplantede laetraeer, samt forskelling udtynding og gødskning af aldre traeer i laehegn. [Experiments with weeding and fertilizing of newly planted shelterbelts and varying thinning-out and fertilizing of old windbreak-trees.] Tidsskr. Planteavl 71: 231-245, illus. [In Danish. English summary.]

938. Kohlbrenner, P. J., and Schuerch, C.
1959. Benzene-alcohol soluble extractives of Sitka spruce. J. Organ. Chem. 24(2): 166-172, illus.

939. Kozlowski, T. T., Hughes, J. F., and Leyton, L.
1967. Movement of injected dyes in gymnosperm stems in relation to tracheid alignment. Forestry 40(2): 207-219, illus.

The path of upward movement of acid fuchsin dye was traced in pole-sized stems of Japanese larch, European larch, Lawson cypress, Sitka spruce, Norway spruce, and Scots pine.

940. Krajina, V. J.
1958-59. Ecological requirements of Douglas-fir, western hemlock, Sitka spruce, and western redcedar. Univ. Brit. Columbia, Dep. Biol. & Bot., 3 pp.

Describes a greenhouse experiment designed to obtain a better understanding of the ecological differences between the species listed in title. Author concludes that along the coast of the open Pacific Ocean, Sitka spruce, requiring great amounts of available magnesium, established pure stands under the influence of oceanic spray; therefore Sitka spruce grows well in alluvial soils rich in magnesium minerals and may even vegetate under the influence of brackish water rich in magnesium.

941. _____ (ed.)
1963. 1962 progress report National Research Council grant No. T-92. Ecology of the forests of the Pacific Northwest. Univ. Brit. Columbia, Dep. Biol. & Bot., 105 pp.

942. _____
1964. 1963 progress report National Research Council grant No. T-92. Ecology of the forests of the Pacific Northwest. Univ. Brit. Columbia, Dep. Biol. & Bot., 94 pp.

943. _____
1965. Ecology of western North America. Vol. 1. Univ. Brit. Columbia, Dep. Bot., 112 pp., illus.

Presents a collection of papers with emphasis on ecology of British Columbia and including coastal Sitka spruce.

944. _____
1965. 1964 progress report, National Research Council grant No. T-92. Ecology of the Pacific Northwest and of western Canadian arctic and subarctic. Univ. Brit. Columbia, Dep. Biol. & Bot., 18 pp.

945. _____
1965. 1965 progress report, National Research Council grant No. T-92. Ecology of the Pacific Northwest and of western Canadian arctic and subarctic. Univ. Brit. Columbia, Dep. Bot., 31 pp., illus.

Describes a preliminary survey of Sitka spruce communities on Vancouver Island. A 3-year project will be carried out to improve understanding of the structure and environmental relationships of different plant communities in habitats where Sitka spruce is the dominant tree.

946. _____
1966. 1966 progress report, National Research Council grant No. T-92. Ecology of the Pacific Northwest and of western Canadian arctic and subarctic. Univ. Brit. Columbia, Dep. Bot., 41 pp., illus.

947. Krajina, Vladimir J.
1959. Bioclimatic zones in British Columbia. Univ. Brit. Columbia Bot. Ser. 1, 47 pp., illus.

Classifies bioclimatic zones as characterized by vegetation types and including Sitka spruce forest.

948. _____ (ed.)
1965. Biogeoclimatic zones and classification of British Columbia. *In* Ecology of western North America. Vol. 1, pp. 1-17. Univ. Brit. Columbia, Dep. Bot.

949. Kramer, H.
1961. Die Verwendung dér Oberhöhe in der Foresteinrichtung. [The use of top height in management.] Allg. Forst- und Jagdzeit. 132(5): 122-129, illus. [In German. English summary.]

950. _____
1966. Crown development in conifer stands in Scotland as influenced by initial spacing and subsequent thinning treatment. Forestry 39(1): 40-58, illus.

This paper deals with the different influences affecting the development of the crown percent in Norway spruce, Sitka spruce, and Douglas-fir stands and gives for these three species development curves of crown percent according to top height, thinning grade, and quality class. It shows the effect of different thinning grades on the crown surface (and crown volume) of the mean tree and the whole stand, together with the relationship between volume increment and crown surface (and volume). The contribution of the different canopy classes to the total increment of the stand is assessed. Finally the relevance which these findings might have on thinning techniques is considered. (Author's summary.)

951. Krause, Aurel.
1956. The Tlingit Indians. Results of a trip to the northwest coast of America and the Bering Straits. (Transl. Erna Gunther.) 310 pp., illus. Seattle: Univ. Wash. Press.

Describes spruce-hemlock forests of southeast Alaska and use of trees by the natives. Sitka spruce was used by the aboriginal Tlingit Indians for dugout canoes, hats, boxes; baskets were woven spruce root. The resin was used externally for treating sores, and heated seeds were used to cure toothache.

952. Krause, Robert L.
1954. Iron stain from metal fastenings may accelerate decay in some woods. J. Forest Prod. Res. Soc. 4(2): 103-111, illus.

953. Kreutzer, K.
1961. Wurzelbildung junger Waldbäume auf Pseudogleyböden. [Root formation by young forest trees on pseudogley soils.] Forstwiss. Central. 80(11/12): 356-392. [In German.]

Sitka spruce was not useful as an admixture in Norway spruce stands to improve root penetration into lower layers of pseudogley soils.

954. Krygier, James T., and Ruth, Robert H.
1961. Effect of herbicides on salmonberry and on Sitka spruce and western hemlock seedlings. Weeds 9(3): 416-422, illus.

The following foliage sprays showed promise for control of salmonberry (*Rubus spectabilis*): the propylene glycol butyl ether (PGBE) esters of 2, 4, 5-TP and 2, 4, 5-T; the butoxy ethanol formulations of the same herbicides; and solubilized acid and solubilized poly-glycol esters of 2, 4, 5-T. Amitrol also was effective, especially added to 2, 4-D, with or without 2, 4, 5-T. Most selective was the PGBE ester of 2, 4, 5-T (2 and 4 pounds per 100 gallons of water with 5-percent kerosene), which did not damage Sitka spruce and western hemlock seedlings. Amine formulations were ineffective on *R. spectabilis*, and damaged hemlock. 2, 4-D, 2-(2, 4-DP) and 2, 3, 6-TBA were unsatisfactory. (From author's summary.)

955. Kuchler, A. W.
1964. Potential natural vegetation of the conterminous United States. Amer. Geogr. Soc. Spec. Pub. 36, 116 pp., illus., plus map.

Consists of a large map of the United States showing major vegetation types, together with a manual describing the vegetation units. Each unit is described and illustrated, and a bibliography is included. Sitka spruce is shown to be a component of the spruce-cedar-hemlock forest, located along the coasts of Washington and Oregon, and occasionally on western slopes of the Cascade Range.

956. Kukachka, B. Francis.
1960. Identification of coniferous woods. Tappi 43: 887-896, illus.

Instructions are given here in the sequential use of primary diagnostic features in the identification of coniferous woods including Sitka spruce. A data chart or marginally perforated cards may be used. Microscopic features are necessarily emphasized because of the greater accuracy obtainable through their use.

957. Kumler, Marion Lawrence.
1963. Succession and certain adaptive features of plants native to the sand dunes of the Oregon coast. 149 pp., illus. (Ph.D. thesis on file at Oregon State Univ.)

958. Kuramoto, R. C.
1965. Plant associations and succession in the vegetation of the sand dunes of Long Beach, Vancouver Island. (M.S. thesis on file at Univ. Brit. Columbia.)

959. Lacassagne, Marcel.
1934. Etudes morphologique, anatomique, et systematique du genre *Picea*. [Studies in morphology, anatomy, and systematization of the genus *Picea*.] Trav. Lab. Forest. Toulouse, t. 2, vol. 3, art. 1, 292 pp.

Reports exhaustively on the genus *Picea* from the morphological and taxonomic standpoint, including a history of the genus, full description of each species, and identification key.

960. Ladefoged, Kjeld.
1938. Frostringsdannelser i vaarveddet hos unge Douglasgraner, Sitkagraner og laerketraeer. [Formation of frost rings in the spring wood of young Douglas-fir, Sitka spruce, and larch.] Forstl. Forsogsv. Danmark 102(15): 97-112 plus 12 figs. [In Danish.]

961. Lafond, Andre.
1962. Forest fertilization in Canada. Laval Univ. Forest Res. Found. (Quebec) Bull. 5, 46 pp., illus.

962. Laiho, Olavi.
1965. Further studies on the ectendotrophic mycorrhiza. Acta Forest. Fenn. 79(3): 1-35, illus.

Coniferous seedlings in nurseries and in forests in the United States, Puerto Rico, and in Europe were examined for presence of ectendotrophic mycorrhizae. Although *Picea sitchensis* roots bore only ectotrophic forms, some of these yielded pure cultures of the ectendotrophic fungal symbiont. Further, semiaseptic pure-culture mycorrhiza synthesis with this fungus and *P. sitchensis* produced ectotrophic mycorrhizae.

963. Laing, E. V.
1932. Studies on tree roots. Great Brit. Forest. Comm. Bull. 13, 73 pp. plus 17 plates.

Discusses types of mycorrhizae, their relationship to tree roots and to soil conditions, problems of establishment of Sitka spruce and other species on peat soils in Britain, as well as improvement of conditions for mycorrhizal formation through application of fertilizers.

964. _____
1947. Preliminary note on a disease of Sitka spruce in Cairnhill plantations, Durris, Kincardineshire (*Picea sitchensis* Carr.). Forestry 21(2): 217-220.

A disease on plantations was noted after brashing and pruning and has been found to be caused by *Nectria curcurbitula* Ft.

965. _____
1951. Botanical studies of variation in certain conifer species. *In* Report on forest research for the year ended March 1950. Great Brit. Forest. Comm., p. 124. London: H. M. Stationery Office.

966. Langner, W.
1959. Ergebnisse einiger Hybridierungsversuche zwischen *Picea sitchensis* (Bong.) Carr. und *Picea omorika* (Pancic) Purkyne. [Results of some trials of hybridization between *P. sitchensis* and *P. omorika*.] Silvae Genet. 8(5): 138-143, illus. [In German. English summary.]

Crosses, carried out in both directions, resulted in very few seeds, but these showed normal vitality. Hybrids from 1 year's trials exhibited hybrid vigor but those from other years did not. Hybrids were clearly intermediate between the parents in reaction to snow, to frost susceptibility, and to formation of leading shoot.

967. Larsen, C. Muhle.
1955. The seasonal variation in the natural rooting capacity of cuttings of Norway spruce and Sitka spruce. Z. Forstgenet. 4(3): 69-80, illus.

Reports on experiments made at the Royal Veterinary and Agricultural College's Arboretum, Horsholm, Denmark. Young twigs of the current year's growth were collected from lateral branches of Norway and Sitka spruce. Cuttings were taken in the period from the beginning of June to mid-April of the following year, propagated in cold frames, and examined the following autumn. Seasonal variations were noted in rooting ability, in the number and length of roots, and in the formation of new shoots. Seasonal variations are due largely to environmental growth conditions but also to length of cuttings. The only difficult period for rooting is at flushing, but the best time for taking cuttings under Danish conditions is early spring or the months of June and July, so that rooting can take place before winter.

968. Larsen, C. Syrach.
1937. The employment of species, types, and individuals in forestry. Veterinaer-og Landbohøjsk. Aarsskr., pp. 69-222 plus 7 plates.

969. _____
1943. Erfaringer med udenlandske traearter i Dansk skovbrug. [Experience with exotic tree species in Danish forestry.] Svenska Skogsvforen. Tidskr. 41: 166-199, illus. [In Danish.]

From the beginning of the nineteenth century up to the present time, the forested area of Denmark has increased from 4 percent to 8.2 percent of the total land area. This has been due largely to the planting of heathland and "kilt" (downs) with exotics. Sitka spruce has been used to a small extent.

970. Larsen, N. J.
1945. Sitkagran X Hvidgran. [Sitka spruce X white spruce.] Dansk Skovforen. Tidsskr. 30:450-451. [In Danish.]

The author reports that almost all the plants brought to his district as Sitka spruce and now in 7- to 12-year-old plantations are mainly Sitka X white spruce.

971. Latham, J.
1952. Timber for aeroplane construction--strength properties of Sitka spruce. *In* Selected government research reports, vol. 8, pp. 21-31, illus. London: H. M. Stationery Office.

Essential strength properties of Sitka spruce have been defined and an investigation made of possible direct application, based on 8,200 tests. The usefulness of brittleness tests has been evaluated, and recommendations are made. The question of design stresses is discussed.

972. _____
1952. Hair checks and imperfections in Sitka spruce laminae. *In* Selected government research reports, vol. 8, pp. 123-134, illus. London: H. M. Stationery Office.

Gives results of tests to determine the influence of hair checks on the strength of laminated Sitka spruce nose rib bends; to examine the effect of imperfections in sliced laminae; and to compare the relative merits of sliced and sawn laminae.

973. Laurent, T. H.
1966. Dwarfmistletoe on Sitka spruce--a new host record. Plant Dis. Rep. 50(12): 921.

A Sitka spruce infected by dwarf mistletoe (*Arceuthobium campylopodum* f. *tsugensis* (Rosendahl) Gill) was found on Chichagof Island, Alaska. The host, a 10-foot sapling, was in the understory of a western hemlock stand. Dwarf mistletoe infections were present on almost every hemlock in the stand. The specimen was associated with witches'-broom form, typical of infections found on western hemlock.

974. Lavers, Gwendoline M.
1966. The strength properties of timbers. Great Brit. Forest Prod. Res. Lab. Bull. 50, 32 pp., illus.

Describes equipment and methods used for testing woods and tabulates mechanical properties of many woods including Sitka spruce.

975. Law, Frank.
1957. The effect of afforestation upon the yield of water catchment areas. J. Inst. Water Eng. 11(3): 269-276.

In experiments from July 1955 to July 1956, a lysimeter was formed by building a concrete wall around part of a small, dense plantation of Sitka spruce at the Stocks Reservoir, Slaidburn, Yorkshire, and measurements were made of runoff, stemflow, and precipitation. Interception values ranged from 36 to 43 percent with little difference between winter and summer.

976. _____
1958. Measurement of rainfall, interception and evaporation losses in a plantation of Sitka spruce. Int. Ass. Hydrol. Eleventh Gen. Assembly Proc. (Toronto) 1957: 397-411, illus.

977. Lawrence, Donald B.
1958. Glaciers and vegetation in southeast Alaska. Amer. Sci. 46(2): 89-122, illus.

Traces vegetation development from the pioneer stage following ice recession through forest of spruce and hemlock to muskeg and pit pond formation.

978. Lawrence, William H., Kverno, Nelson B., and Hartwell, Harry D.
1961. Guide to wildlife feeding injuries on conifers in the Pacific Northwest. Western Forest. & Conserv. Ass., 44 pp., illus.

979. Leathart, P. S.
1967. A forestry tour in Iceland. Quart. J. Forest. 61(1): 5-24, illus.

980. Lejeune, R. R.
1962. A new B.C. reforestation problem. Brit. Columbia Lumberman 46(10): 30.

Damage to natural spruce regeneration on the Queen Charlotte Islands was caused by the weevil *Steremnius carinatus*, apparently native to the coastal forests.

981. Lembcke, G.
1961. Der Anbau von *Picea sitchensis* und *Pinus strobus* im Diluvialgebiet der Deutschen Demokratischen Republik und im Harz. [Growing *P. sitchensis* and *P. strobus* in the Diluvial region of E. Germany and in the Harz Mountains.] Tag. Deut. Akad. der Landwirtschaftswiss. (Berlin)26: 123-137, illus. [In German. English summary.]

Describes growth of about 50 Sitka spruce sample plots, mostly in the coastal region of Mecklenburg, and about 40 plots of *Pinus strobus*, mostly in the Lausitz region, aged mainly 20 to 60 years. Stem form was analyzed and volume tables were constructed. Height growth of Sitka spruce was best on sand and loam with a sufficiently high water table, and superior to Norway spruce. *Neomyzaphis abietina* attacked Sitka spruce but was not a serious problem.

982. Lemke, Paul Arenz.
1964. The genus *Aleurodiscus* (sensu stricto) in North America. Can. J. Bot. 42(2): 213-282.

983. LePont, P., and Pardé, J.
1962. Les resineux dans le nord de la Seine-Maritime. [Conifers in the north of Seine-Maritime.] Rev. Forest. Franc. 14(12): 979-993. [In French.]

Describes conifer plantations on clay-with-flints in the Dieppe region. Sitka spruce is the most successful species, with a mean annual increment of 16 to 18 cubic meters per hectare at 40 to 50 years; Douglas-fir does almost as well, and Japanese larch attains 13 cubic meters per hectare. Mean annual increment of the local climax beech forest is only 8 cubic meters per hectare.

984. Lesko, Gyorgy Laszlo.
1961. Ecological study of soils in the coastal western hemlock zone. 141 pp. (M.S. thesis on file at Univ. Brit. Columbia.)

Examinations of macroscopic soil properties and topographic position were used as a basis for delineation of forest associations in the coastal western hemlock zone, including Sitka spruce. The most important edaphic factors differentiating the forest association were moisture regime, soil depth, organic matter-N ratio, and K concentration.

985. Levisohn, I.
1963. Über Mykorrhizen und Pseudomykorrhizen. [About mycorrhizas and pseudomycorrhizas.] Mykorrhiza, Int. Mykorrhiza Symp. (Weimar) 1960: 27-34. [In German, English summary.]

Discusses pseudomycorrhizae of *Picea sitchensis*.

986. Levisohn, Ida.
1954. Aberrant root infections of pine and spruce seedlings. New Phytol. 53(2): 284-290 plus 5 photos.

In pine and spruce seedlings from forest nurseries in Great Britain, heavy root invasions by mycelia closely related to *Rhizoctonia sterilis*

are frequently encountered. In spruce, they are characterized by the absence of a mantle and the presence of a very coarse intercellular net. In Sitka spruce, reduced vigor and growth caused by the aberrant infection is not pronounced.

987. _____
1956. Growth stimulation of forest tree seedlings by the activity of free-living mycorrhizal mycelia. Forestry 29(1): 53-59 plus 2 plates.

988. _____
1965. Mycorrhizal investigations. *In* Experiments on nutrition problems in forest nurseries, Blanche Benzian [ed.]. Great Brit. Forest. Comm. Bull. 37, 1: 228-235, illus.

Reports on mycorrhizal associations with Sitka spruce in forest nurseries in Great Britain as affected by fertilizer applications.

989. Lewinski, Von E. v.
1966. Möglichkeiten zur Mechanisierung bei der Aufforstung feuchter Grenzertragsböden--Ein Erfahrungsbericht. [Possibilities for mechanization in the afforestation of moist marginal lands: an empirical report.] Aus Walde 12: 57-66, illus. [In German.]

990. Leyton, L.
1950. The growth and mineral nutrient relations of trees growing on Calluna-dominated sites. Seventh Int. Bot. Congr. Pap. (Stockholm), pp. 251-252.

991. _____
1951. Nutrient uptake of conifers. *In* Report on forest research for the year ended March 1950. Great Brit. Forest. Comm., pp. 118-119. London: H. M. Stationery Office.

Describes experiments on the effect of pH on growth of Sitka spruce in water cultures.

992. _____
1951. Mineral nutrient studies in heathland plantations. *In* Report on forest research for the year ended March 1950. Great Brit. Forest. Comm., pp. 127-129. London: H. M. Stationery Office.

993. _____
1952. The effect of pH and form of nitrogen on the growth of Sitka spruce seedlings. Forestry 25(1): 32-40, illus.

The effect of pH and form of nitrogen (NH4 and NO3) on the growth of Sitka spruce seedlings has been investigated on nutrient culture solutions over the range of pH 3-7. In both nitrogen series, the reaction for optimum growth of both shoot and root appears to lie between pH 4 and 5. Above and below this range there is a decrease in dry-weight production accompanied by increasingly abnormal root development. The form of nitrogen supplied appeared to have little effect on total growth at equivalent reactions, but from the root/shoot ratios it seems that nitrate nitrogen stimulates a greater relative root production than does ammonia nitrogen. (From author's summary.)

994. _____
1953. Growth and nutrition in heathland plantations. *In* Report on forest research for the year ended March 1952. Great Brit. Forest. Comm., pp. 117-119. London: H. M. Stationery Office.

Significant changes in growth and nutrition of planted trees occurred due to removal of heather (screefing) and the application of ground mineral phosphates.

995. _____
1954. The growth and mineral nutrition of spruce and pine in heathland plantations. Imp. Forest. Inst. (Univ. Oxford) Pap. 31, 109 pp., illus.

Poor growth of Sitka spruce in young plantations on upland heaths is attributed to nitrogen deficiences in the soil, aggravated by heather vegetation. Temporary improvement in growth may be brought about either by application of nitrogenous fertilizer or by removal of the heather vegetation. On some sites, manganese also appears to play an important role in growth increases.

996. _____
1955. The influence of artificial shading of the ground vegetation on the nutrition and growth of Sitka spruce (*Picea sitchensis* Carr.) in a heathland plantation. Forestry 28(1): 1-6, illus.

A marked stimulus has been obtained by shading the heather vegetation surrounding trees, by means of wooden laths. The increased growth was accompanied by significant increases in the concentration of nitrogen, ash, and manganese in the needles, indicating a substantial increase in the availability of these nutrients to the trees. A similar shading experiment on plots from which the heather (*Calluna vulgaris* Hull) had been previously removed by screefing produced only doubtful responses. Heather plants growing beneath the laths were found to contain appreciably lower concentrations of nutrients in the foliage than unshaded plants. While the response of the trees to shading of the ground vegetation is attributed largely to reduced competition by the heather for available nutrients in the soil, especially nitrogen, the mulching effect of the heather in maintaining satisfactory moisture conditions during dry periods is also involved. These findings offer an explanation for the improvement in the growth of spruce in mixture with nurse trees when the latter form a closed canopy and suppress the ground vegetation. (Author's summary.)

997. _____
1957. The mineral nutrient requirements of forest trees. Ohio J. Sci. 57: 337-345.

Discusses forest tree nutrition using data on Sitka spruce to illustrate main points.

998. _____ and Weatherell, J.
1959. Coniferous litter amendments and the growth of Sitka spruce. Forestry 32(1): 7-13.

The growth of semichecked Sitka spruce on heathland has been stimulated to different degrees by the annual application (1956 and 1957) of litter of Scots pine, Corsican pine, lodgepole pine, Japanese larch, and Sitka spruce at rates corresponding to normal plantation conditions, following a heavier initial application (1955). Foliar analysis suggests that the response is at least partially attributable to the influence of the litters on the nitrogen nutrition of the spruce, and differences between litters appear determined by their nitrogen content. (From author's summary.)

999. Leyton, Leonard.
1958. The relationship between the growth and mineral nutrition of conifers, pp. 323-345, illus. *In* The physiology of forest trees, Kenneth V. Thimann, William B. Critchfield, and Martin H. Zimmermann [ed.]. New York: The Ronald Press Co.

Discusses the value of foliar analysis as a reliable method for diagnosis of nutritional status. Author concludes that with proper sampling, foliar analysis provides a reasonable guide to particular mineral deficiences limiting tree growth and to interpretation of field observations. Information on needle composition generally provides little guidance to the degree of response to a given increase in nutrient supply because of complex interaction of many factors. Sitka spruce was one of the experimental species.

1000. Liang, C. Y., Bassett, K. H., McGinnes, E. A., and Marchessault, R. H.
1960. Infrared spectra of crystalline polysaccharides. VII. Thin wood sections. Tappi 43: 1017-1024, illus.

The infrared spectra of wood sections have been recorded in the untreated state and after treatment for removal of lignin and hemicellulose. Differences between the spectra of hardwood (*Acer rubrum*) and softwood (*Pseudotsuga taxifolia, Tsuga heterophylla, Picea sitchensis, Thuja plicata*) sections were correlated with the greater glucomannan and smaller 4-O-methylglucuronoacetylxylan content of the latter. (From author's summary.)

1001. Liang, Ernest V.
1927. Water content of seedlings and transplants in the nursery. Scot. Forest. J. 41: 26-35, illus.

1002. Liddicoet, A. R., and Righter, F. I.
1960. Trees of the Eddy Arboretum. USDA Forest Serv. Pacific Southwest Forest & Range Exp. Sta. Misc. Pap. 43, 41 pp., illus.

1003. Lindquist, Bertil.
1948. Genetics in Swedish forestry practice. 173 pp., illus. Stockholm: Svenska Skogsvårdsforeningens Forlag.

Strangulation by means of a thin iron wire wrapped several times around the stem has been shown to stimulate flowering of Sitka spruce to a high degree.

1004. Lindsay, A. D.
1932. Sitka spruce. Commonwealth Forest. Timber Bur. (Canberra) Leafl. 24a, 8 pp.

Reviews the silvics of Sitka spruce in its natural range and outside its native habitats and concludes that it has value for plantations in Australia.

1005. Lines, R.
1953. The Scottish gale damage. Irish Forest. 10(1): 3-15.

1006. _____
1956. Provenance experiments. *In* Report on forest research for the year ended March 1955. Great Brit. Forest. Comm., pp. 35-36. London: H. M. Stationery Office.

Gives notes on provenance trials of lodgepole pine, Sitka spruce, and Douglas-fir. A vivid yellow and purple discoloration was noted on some Sitka spruce, but the cause has not been discovered.

1007. _____
1964. Early experiments on the provenance of Sitka spruce. *In* Report on forest research for the year ended March 1963. Great Brit. Forest. Comm., pp. 136-146. London: H. M. Stationery Office.

Describes results of many provenance tests in Europe and Britain with Sitka spruce from throughout the tree's natural range.

1008. _____ and Aldhous, J. R.
1961. Provenance studies: Sitka spruce. *In* Report on forest research for the year ended March 1960. Great Brit. Forest. Comm., pp. 43-44. London: H. M. Stationery Office.

Describes early growth of 12 provenances ranging from Hollis, Alaska, to southern Oregon. Differences in height growth and phenology are mentioned. Seven planting sites have been chosen in the most important parts of the Sitka spruce range in Britain.

1009. _____ and Mitchell, A. F.
1965. Provenance: Sitka spruce. *In* Report on forest research for the year ended March 1964. Great Brit. Forest. Comm., pp. 31-32. London: H. M. Stationery Office.

Describes trials of Sitka spruce from Alaska, British Columbia, Washington, and Oregon.

1010. _____ and Mitchell, A. F.
1966. Provenance: Sitka spruce. *In* Report on forest research for the year ended March 1965. Great Brit. Forest. Comm., pp. 38-43. London: H. M. Stationery Office.

Includes report on a provenance experiment with Sitka spruce planted in 1960-61. Seed sources ranged from latitude 46° to 60-1/2° N.

1011. _____ and Mitchell, A. F.
1966. Differences in phenology of Sitka spruce provenances. *In* Report on forest research for the year ended March 1965. Great Brit. Forest. Comm., pp. 173-184, illus. London: H. M. Stationery Office.

Small unreplicated demonstrations were planted in 1959 and 1960 with 12 provenances of Sitka spruce ranging from Alaska to Oregon, over a range of latitude from 60-1/2° to 43° N. These demonstrations were at four sites at latitudes from 51° N. to 57-1/2° N. They were assessed each year for date of flushing, and their height growth was measured at weekly intervals during the 1959-61 growing seasons. Date of flushing varied more between individual trees than between provenances; the latter differences were small, but the northern provenances tended to flush over a longer period than did the southern ones. The growth pattern also showed considerable variation within a provenance, but the most striking feature was the early cessation of growth on the provenances from northern Alaska, which stopped growing in midsummer when the southern provenances had completed only half of their annual height growth. Photoperiod or critical day length is suggested as the cause of growth cessation, as it was also found that the average date when the provenances stopped growing was related to latitude of the experimental site; the provenances continued to grow for the longest period at the most northerly site. (Author's summary.)

1012. _____, Neustein, S. A., Henman, D. W., and Atterson, J.
1966. Species trials. *In* Report on forest research for the year ended March 1965. Great Brit. Forest. Comm., pp. 33-34. London: H. M. Stationery Office.

The first of a small series of plots comparing *Picea* X *lutzii* with Sitka spruce was planted in eastern Britain. Theoretically, the hybrid may withstand moisture stress better than Sitka spruce.

1013. _____ and Nimmo, M.
1966. Long-term mixtures. *In* Report on forest research for the year ended March 1965. Great Brit. Forest. Comm., pp. 35-38. London: H. M. Stationery Office.

Describes 10-year survival and growth of mixed Sitka spruce-western hemlock plantations on four exposed sites in southern Wales. Sitka spruce survived better and grew taller than western hemlock. Western hemlock seemed to benefit from the shelter of Sitka spruce in the mixed as compared with pure plantations.

1014. Lines, Roger.
1965. Provenance and the supply of forest tree seed. Quart. J. Forest. 59(1): 7-15.

Suitable and unsuitable sources for nine tree species, including Sitka spruce, are given. Generally suitable provenances for Sitka spruce plantings in Britain are Queen Charlotte and Vancouver Island, B. C.; Washington, suitable in southwest England; California generally unsuitable. Alaskan provenances may suffer from autumn frost. All provenances may suffer from spring frost. General findings applicable to all species are discussed.

1015. Little, Elbert L., Jr.
1944. Notes on nomenclature in Pinaceae. Amer. J. Bot. 31(9): 587-596.

1016. _____
1949. To know the trees; important forest trees of the United States. U.S. Dep. Agr. Yearbook 1949: 763-814, illus.

1017. _____
1953. A natural hybrid spruce in Alaska. J. Forest. 51: 745-747.

Describes *Picea lutzii*, a new natural hybrid between *P. glauca* and *P. sitchensis* from the Kenai Peninsula, Chugach National Forest, based on herbarium material. The hybrid, which rose naturally from plantations, has been artificially produced in Denmark, where Fabricius and Larsen have recorded and illustrated it. Very fast growth is reported from Sweden.

1018. _____
1953. Checklist of native and naturalized trees of the United States (including Alaska). U.S. Dep. Agr. Handbook 41, 472 pp.

1019. Livingstone, Burton E., and Shreve, Forrest.
1921. The distribution of vegetation in the United States, as related to climatic conditions. Carnegie Inst. Pub. 284, 590 pp.

Sitka spruce inhabits only the northwestern hygrophytic forest.

1020. Lockhart, R. E.
1964. Regeneration following clearcut timber harvest in southeastern Alaska. Western Forest. & Conserv. Ass., Portland, Oreg. Western Reforest. Coord. Comm. Annu. Proc. 1964: 3-5.

1021. _____
1966. Alaska-sized timber sale. J. Forest. 64: 83-86, illus.

1022. Lodewick, J. Elton, and Harrar, Ellwood S.
1937. What wood is that? Timberman 38(8): 33-40, (9): 18-24, illus.

1023. Løfting, E. C. L.
1937. Hedeskovenes Foryngelse: V. Rodfordaerverangrebenes betydning for Sitkagrans anvendelighed I klitter og heder. [The significance of the attacks of *Polyporus annosus* to the suitability of the Sitka spruce for dunes and heaths.] Forst. Førsogsv. Danmark 14(2): 133-160, illus. [In Danish. English summary.]

1024. Løken, A.
1958. Froets spiring hos Sitkagran og lerk. [Germination of Sitka spruce and larch.] Arsskr. Norske Skogplantesk 1957: 28-35. [In Norwegian.]

Stratification for 7, 15, 30, and 60 days considerably increased both germinative energy and capacity of Sitka spruce and Japanese larch, the effect increasing with duration of stratification.

1025. _____
1959. Spireforsøk i kjølerom. [Germination experiments in a refrigerator chamber.] Medd. Vestlandets Forstl. Forsoekssta. 33: 1-19. [In Norwegian. English summary.]

Scots pine, Norway and Sitka spruce, and Japanese larch seed were tested in a refrigerator kept at 2 to 4° C. In the first experiment, two lots of Sitka spruce seed were germinated in sand in a germinating bell. One lot, exposed to constant light, showed germination of 13.5 and 17.8 percent after

4 and 5 months, respectively, whereas the second lot, kept in complete darkness, showed no sign of germination, possibly because of heavy mold which cemented the seed and sand into an airtight cake. In another series of experiments, seeds of three provenances of pine, four each of Norway and Sitka spruce, and one of Japanese larch, were germinated in a simplified Jakobsen germinator, lit by two 40-watt lamps suspended 70 centimeters above the germination layer. Germination started in pine after 70 days, followed by Norway spruce (70 to 80 days), larch (100 to 120 days), and Sitka spruce (100 to 140 days). Most of the pine seed (81 to 92 percent) had germinated after 220 days; this point was not reached by the other species for 380 days. It is possible that with germination at these low temperatures there is some relationship between date of seed dispersal and speed and extent of germination.

1026. _____
1959. Stratifisering av Sitkagranfrø. [Stratification of Sitka spruce seed.] Arsskr. Norske Skogplantesk 1958: 47-50. [In Norwegian.]

Experiments were made in 1958 with seed from American sources collected in 1957 which germinated much more slowly than Norwegian seed. Seed was stratified for 15, 30, or 60 days either on filter paper in a petri dish or in a cone of filter paper resting in the neck of a widemouth bottle, and the number of seeds germinating in a Jakobsen germinator after 7, 15, and 21 days was determined. Results are tabulated. Seed stratified for 15 and 30 days germinated faster, and those stratified for 60 days slower, than untreated controls. The germination percent of some lots stratified 15 and 30 days was higher and for others lower than in the controls; stratification for 60 days considerably reduced germination compared with controls. A study of the nongerminating seed showed that few were either still living or empty; the percent of dead seed increased considerably with increasing length of stratification, and microscopic examination showed that the seed had been attacked by fungus.

1027. Long-Bell Lumber Company.
1930. Tree planters' guide; the climate and vegetation of the North Pacific coast region. 9 pp, illus. Longview, Wash.

1028. Lotspeich, Fredrick B.
1956. Soil-plant relationships on the Quillayute Prairie in western Clallam County, Washington. 114 pp. (Ph.D. thesis on file at Wash. State Coll.) (Diss. Abstr. 17(1): 3.)

1029. _____ , Secor, Jack B., Okazaki, Rose, and Smith, Henry W.
1961. Vegetation as a soil-forming factor on the Quillayute physiographic unit in western Clallam County, Washington. Ecology 42(1): 53-68, illus.

Vegetation of the prairie is chiefly herbaceous and is dominated by bracken fern. The adjacent climax forest in the spruce-hemlock coastal strip has western hemlock as its dominant tree species. Sitka spruce is shown to be a one-generation seral species in these areas.

1030. Low, A. J.
1964. Compression wood in conifers: a review of literature. Forest. Abstr. 25(3/4): xxxv-xliii, xlv-li.

1031. _____ and Taylor, E. G. M.
1967. Growth problems in pole-stage Sitka spruce. *In* Report on forest research for the year ended March 1967. Great Brit. Forest. Comm., pp. 78-79. London: H. M. Stationery Office.

Two Sitka spruce stands were thinned by removing 30 percent of the standing basal area, in the first by removing dominant and codominant trees, and in the second by removing only small-crowned trees from the lower canopy. Subsequent blowdown was greatest in the stand thinned from above and least in a nearby check area, indicating that thinning from above is undesirable in windthrow-susceptible areas.

1032. Low, J. D., and Gladman, R. J.
1960. *Fomes annosus* in Great Britain; an assessment of the situation in 1959. Great Brit. Forest. Comm. Forest Rec. 41, 22 pp. plus 21 figs.

1033. Lowenberger, Frederick J.
1965. Some silvical and mensurational characteristics of Sitka spruce in the Queen Charlotte Islands. 74 pp., illus., plus map. (B.S. in Forestry thesis on file at Univ. Brit. Columbia.)

Concludes that Sitka spruce plantations do not fail because of grass competition on cutover bottom lands, although grass causes some deformations in young seedlings. Seedling condition was better and browsing less on unburned rather than burned areas, although growth was the same. Burning did not influence distribution of a seedling weevil (*Steremnius carinatus* Boh.). In the Juskatla (Queen Charlotte Islands) area, Sitka spruce is a tolerant tree, and stands are all-aged. Present site index tables for western hemlock are not applicable to spruce as the forms of the two species are different.

1034. Lowry, A. L.
1956. Sitka spruce at Bachelors Lodge. Irish Forest. 13(2): 70-71, illus.

Describes growth at 16 years of Sitka spruce planted in cleared woodland at 9- by 9-foot spacing.

1035. Lunak, S. E.
1918. Effect of varying certain cooking conditions in the production of sulphite pulp from spruce. U.S. Dep. Agr. Bull. 620, 24 pp., illus.

1036. Lutz, H. J.
1930. Observations on invasion of newly formed glacial moraines by trees. Ecology 11: 562-567, illus.

Presents observations made on the vegetational development on newly formed glacial moraines in southwestern Alaska. Pioneer species are *Picea sitchensis*, *Tsuga mertensiana*, *Alnus sinuata*, and *Populus tacamahaca*, in order of abundance.

1037. _____
1951. The concentration of certain chemical elements in the soils of Alaskan archaeological sites. Amer. J. Sci. 249: 925-928.

Determinations were made in the soils of two southeast Alaskan native village sites and in adjacent soils bearing natural forest growth. The food used by primitive man in Alaska was largely of animal origin and was relatively high in certain chemical elements. In time, the soil of the village sites was greatly enriched, with the result that there has been a 50-fold to 175-fold increase in phosphorus, a threefold to sevenfold increase in nitrogen, a fourfold to sixfold increase in potassium, and a twofold to twelvefold increase in calcium.

1038. _____
1963. History of Sitka spruce planted in 1805 at Unalaska Island by the Russians. USDA Forest Serv. Northern Forest Exp. Sta. 25 pp., illus.

The first attempt at tree planting in the Aleutian Islands was made in 1805, inspired by the Russian chamberlain, Rezanov. When last examined (1958) 10 trees were still standing, six alive and four dead. Live trees ranged in height from 24 to 28 feet. Seedlings were found up to 300 feet from the trees.

1039. Luxford, R. F.
1944. Strength of glued laminated Sitka spruce made up of rotary-cut veneers. USDA Forest Serv. Forest Prod. Lab. Rep. 1512, 13 pp.

1040. Lyons, C. P.
1952. Trees, shrubs and flowers to know in British Columbia. 168 pp., illus. Toronto and Vancouver: J. M. Dent & Sons (Canada) Ltd.

1041. _____
1956. Trees, shrubs and flowers to know in Washington. 211 pp., illus. Toronto and Vancouver: J. M. Dent & Sons (Canada) Ltd.

1042. Macaulay Institute for Soil Research.
1957. Forest fertilizer trials. Macaulay Inst. Soil Res. Rep. 1956/57: 52.

Analysis of foliage collected in September 1956 from lodgepole pine and Sitka spruce on deep peat at the Lon Mor indicated a positive correlation between height growth and levels of N, K, and Mg in the foliage of both species in plots that had received P at the time of planting, suggesting that these elements were likely to limit growth in larger trees whose initial P requirements had been satisfied.

1043. _____
1959. Tree growth on deep peat. Macaulay Inst. Soil Res. Rep. 1957/58: 44-45.

Use of the pressure-membrane apparatus to investigate the tensions at which moisture is held in peat under trees suggests that although a reserve of available moisture still exists in the relatively dry peat under the largest trees, temporary moisture shortage may be experienced during a dry summer. An investigation has been started on the marked effect of plough ridge depth on the early growth of lodgepole pine and Sitka spruce on peat at Wauchope Forest.

1044. _____
1960. Forest fertilizer trials. Macaulay Inst. Soil Res. Rep. 1958/59: 15.

Analysis of foliage samples collected at the end of the second growing season from lodgepole pine and Sitka spruce in the N/K/Mg fertilizer trials on deep peat at the Lon Mor showed that the spruce, which grew well earlier as a result of repeated P dressings, was suffering from acute K deficiency. Needle K content increased in the plots with K, and needle N content was slightly increased by the N treatment. Diameter growth during the third growing season showed an increase in the plots with K.

1045. _____
1962. Forest soils: nutrient content of peat. Macaulay Inst. Soil Res. Rep. 1960/61: 14.

Twelve deep-peat sites in Scotland were surveyed and samples were analyzed. Results showed that K deficiency in trees occurs earliest where total K content of peat is lowest, and that, in general, responses to phosphate vary inversely with the total P content of the peat. Sitka spruce has shown good early growth only on sites with a total peat N content of more than 2 percent and a relatively high ash content. These results suggest that a chemical survey of newly acquired deep peat areas might eventually be used to estimate suitability for different tree species and the type and amounts of fertilizers required.

1046. McAvoy, B.
1931. Ecological survey of the Bella Coola region. Bot. Gaz. 92: 141-171.

1047. MacBean, A. P.
1949. Silviculture and cutting methods in British Columbia. Forest. Chron. 25(3): 164-169.

A review of the cutting systems and logging methods used and their effect on regeneration of Douglas-fir, hemlock, Sitka spruce, and ponderosa pine.

1048. McCambridge, W. F.
1956. Effects of black-headed budworm feeding on second-growth western hemlock and Sitka spruce. Soc. Amer. Forest. Proc. 1955: 171-172.

A heavy attack by *Acleris variana* on western hemlock and Sitka spruce in southeast Alaska was studied. Reduction in radial growth appears to be independent of budworm damage. In most cases where tree tops were killed, both species appear to be forming new leaders.

1049. _____
1957. A record of spruce cone insects in Alaska. USDA Forest Serv. Alaska Forest Res. Center Tech. Note 34, 2 pp.

Tabulates results of cone dissections and rearing of larvae from cones of *Picea sitchensis*, *P. sitchensis* X *lutzii*, and *P. glauca*.

1050. _____ and Downing, G. L.
1960. Black-headed budworm. U.S. Dep. Agr. Forest Pest Leafl. 45, 4 pp., illus.

1051. McComb, Fremont, and Munger, T. T.
1940. Roadside windfall in spruce-hemlock. USDA Forest Serv. Pacific Northwest Forest & Range Exp. Sta. Forest Res. Note 31, p. 8.

A 4-mile survey of roadsides in a 90-year-old dense spruce-hemlock stand on the Cascade Head Experimental Forest showed over four times as much windfall within 100 feet of roads as between 100 to 200 feet of roads.

1052. McConaghy, S.
1962. The effects of fertilizers on the growth and composition of Sitka spruce. Irish Forest. 19(1): 56-59.

1053. _____, McAllister, J. S. V., Parkin, K. F., and Parker, R. E.
1961. The growth of Sitka spruce on deep peat in Northern Ireland. 1. The effect of fertilizers and other treatments on the growth of young trees. Res. & Exp. Rec. Min. Agr. (Belfast) 10(2): 151-162.

Describes a study of the effects of various treatments on the growth of young Sitka spruce trees on deep peat, with particular reference to the incidence of check. The addition of certain nitrogenous materials to young trees in check produced a temporary improvement in growth and color, but this improvement was not so persistent as that obtained by deepening the main drains and placing the excavated peat around the trees.

1054. McCulloch, Walter F.
1929. Natural regeneration of Sitka spruce on the Queen Charlotte Islands. Forest. Chron. 5(4): 21-23.

Describes a regeneration survey made on all lands cut over during the wartime spruce logging. At least 10 years had elapsed since logging, allowing ample time for early stocking changes, so that the reproduction was considered fairly indicative of the expected mature stand. There is generally good reproduction on the island and fair reproduction of Sitka spruce.

1055. MacDonald, A.
1967. Trial plantations established by the Forestry Commission on the island of Hoy, Orkney. Scot. Forest. 21(3): 163-172.

Sitka spruce, considered one of the best species for exposed sites, proved disappointing.

1056. MacDonald, J.
1928. Growth and yield of conifers in Great Britain. Great Brit. Forest. Comm. Bull. 10, 187 pp., illus.

Contains yield tables for Sitka spruce.

1057. MacDonald, J. A. B.
1953. Thirty years' development of afforestation techniques on difficult ground types in southwest Scotland. Forestry 26(1): 14-21.

Norway and Sitka spruce are the first choice for species to plant on Molinia heath lands following adequate drainage and turnover of turf.

1058. _____
1956. Effect of introducing pine species among checked Sitka spruce on a dry Calluna-clad slope. Scot. Forest. 50: 83-86, illus., plus 1 plate.

Sitka spruce made better growth when planted in mixture with Scots pine than when planted in pure stands.

1059. _____
1963. Thinning to meet today's problems. Forestry 36(2): 165-171.

1060. _____
1967. Norway or Sitka spruce? Forestry 40(2): 129-138.

Norway is the more plastic spruce and can suffer thinner soils and much more drought, but neither spruce is a shallow rooter where soils are good and deep. Of the two, the litter of Sitka is less harmful to the soil. To date there is no evidence that height for height Norway is more stable under high wind pressures, but the belief that it is less sensitive to frost than Sitka is well established. Sitka is far superior to Norway for planting at high altitudes and in exposed places and on Molinia peatlands in Britain, which accounts for the vast preponderance of the American species used in the west and the north of the British Isles. Planting Norway where Sitka could grow well results in only some 75 percent as much volume production. Types of site which each spruce requires and also which each cannot take are considered in detail. (From author's summary.)

1061. _____ and MacDonald, Angus.
1952. The effect of interplanting with pine on the emergence of Sitka spruce from check on heather land. Scot. Forest. 6(3): 77-81, illus.

1062. MacDonald, J. M.
1938. Sitka spruce regeneration at Largie. Scot. Forest. J. 52: 143-144.

1063. MacDonald, James.
1931. Sitka spruce in Great Britain, its growth, production, and thinning. Forestry 5(2): 100-107.

1064. _____
1932. The form of the stem in coniferous trees. Forestry 6: 53-62.

1065. _____
1933. The form of the stem in coniferous trees. Forestry 7(2): 121-129.

Discusses and tabulates form class, root swelling, and bark percentages for several coniferous species including Sitka spruce. Includes a table of bark percentage for Sitka spruce.

1066. _____
1952. The place of northwestern American conifers in British forestry. Sixth Brit. Commonwealth Forest. Conf., Can., 1952; item 7a Silviculture. Great Brit. Forest. Comm., 21 pp.

Western American conifers now account for 23 percent of all conifer plantations in Great Britain. Sitka spruce covers a larger area than any other conifer except Scots pine; Douglas-fir has been extensively used, and increasing use is being made of *Pinus contorta, Tsuga heterophylla, Abies grandis, A. nobilis,* and *Chamaecyparis lawsoniana.* The part played by these species in British forest economy is discussed. Tables are given of the areas occupied by various age classes of each species, and of recorded height growth and volume production at various ages on selected sample plots. Notes are given on the less important forest species. (From author's summary.)

1067. _____, Wood, R. F., Edward, M. V., and Aldhous, J. R.
1957. Exotic forest trees in Great Britain. Great Brit. Forest. Comm. Bull. 30, 167 pp., illus.

Sitka spruce is the most extensively planted exotic in Great Britain. The 1947-49 woodland census showed 167,000 acres, or 9 percent of the entire productive forest area. The species is discussed in detail, including country of origin and provenance, historical notes, extent of planting, climatic requirements, site requirements, establishment techniques (planting and direct seeding), thinning, growth and yield, damage, genetics, natural regeneration, timber, and potentialities in Britain.

1068. MacDonald, J. M.
1956. Thinning Sitka spruce. Scot. Forest. 10(1): 26-30, illus.

Suggests some of the considerations that may apply to the thinning of Sitka spruce plantations in regions of moderate growth. The importance of heavy crown thinning is stressed.

1069. MacDonald, J. Maxwell.
1952. Wind damage in middle-aged crops of Sitka spruce and its prevention. Scot. Forest. 6(3): 82-85.

Gale damage is a serious economic factor on the west coast of Scotland, and Sitka spruce grown in dense even-aged plantations is particularly vulnerable. Suggested counter measures are the development of irregular and mixed crops by crown thinning, strip or group planting, and the planting of very small groups widely spaced over considerable areas, relying on natural regeneration to fill the spaces between groups.

1070. _____ and Lockhart, S. F.
1953. Some early observations on the natural regeneration of conifers in Scotland. Scot. Forest. 7(3): 79-82, 85.

1071. McDowell, D. N.
1955. Pests and diseases of trees and shrubs. Wis. State Dep. Agr. Bull. 330, 88 pp., illus.

Briefly describes *Chrysomyxa ledicola*, a rust which attacks Sitka spruce. Little can be done to control this needle rust under forest conditions.

1072. McElhanney, T. A.
1951. Commercial timbers of Canada, pp. 23-56, illus. *In* Canadian woods; their properties and uses. Ottawa: Queen's Printer.

1073. _____ and Perry, R. S.
1927. Some commercial softwoods of British Columbia; their mechanical and physical properties. Can. Dep. Int. Forest Serv. Bull. 78, 45 pp., illus.

1074. McEvoy, T.
1954. Afforestation of peat soils. Irish Forest. 11(2): 65-75 plus 4 photos.

Gives an account of Irish experiments, based largely on Forestry Commission experience in Great Britain, and differing chiefly in a much more extensive use of lodgepole pine in place of Sitka spruce. A pilot experiment in the afforestation of a blanket bog is described in detail. Paper presented at the International Peat Symposium, Dublin, 1954.

1075. MacGillivray, H. G.
1962. Report on tree improvement at the Acadia Forest Experiment Station, April 1960 - March 1962. Can. Forest. Tree Breeders, 1-14, illus.

Sitka spruce, white spruce, and lots likely to contain hybrids were planted to provide material for breeding, and to see how these lots would perform in east coast areas. Provenances are from Alaska, Canada, and Denmark.

1076. MacGregor, W. D.
1952. Sitka spruce-density survey project. Great Brit. Forest Prod. Res. Lab. Progr. Rep. 1 (Princes Risborough), 6 pp.

Presents density measurements based on ovendry weight and green-volume made on 69 discs taken at various levels from 39 trees in three sample plots in Wales. Mean values show little variation between plots, but the range within plots is high. The oldest plot had the highest and the youngest plot the lowest density. Density becomes lower from 1 foot to 22 feet up the bole of the tree. There is poor correlation between density and annual-ring width, better correlation between density and proportion of summerwood.

1077. McGugan, B. M.
1958. Forest Lepidoptera of Canada, recorded by the forest insect survey. Vol. 1-Papilionidae to Arctiidae. Can. Dep. Agr. Forest Biol. Div. Pub. 1034, 76 pp., illus.

Presents available data on distribution, feeding habits, prevalence, and seasonal occurrence of insects in Papilionidae to Arctiidae families that attack Sitka spruce.

1078. McKay, R.
1957. Note on malformation of Sitka spruce due to drift from hormone weed killer. Irish Forest. 14(2): 98-99.

1079. _____ and Clear, T.
1953. Association of *Rhizina inflata* with group dying of Sitka spruce. Irish Forest. 10(2): 58-59.

Investigation of a typical case of "group dying" in a 30-year-old stand of Sitka spruce showed that roots of all affected trees were completely dead, resin flow was profuse from the base of the stems but there was no stem or butt rot, and the ground around the base of the trees was covered with fructifications of *R. inflata*, a saprophyte that occasionally becomes parasitic.

1080. _____ and Clear, T.
1955. A further note on group dying of Sitka spruce and *Rhizina inflata*. Irish Forest. 12(2): 58-63, illus.

Includes photographs of fructifications of *R. inflata*, enlarged lenticels, and copious resin flow on the stem of a dying tree, and a typical example of group dying.

1081. McKee, M., and Birch, T. C.
1941. Growth of spruce at Conical Hill: a mycorrhizal explanation. New Zealand J. Forest. 4: 311-313.

Of the spruce (*Picea abies* and *P. sitchensis*) planted in Conical Hill State Forest between 1903 and 1916, those in the interior of pure stands are small, undersized trees and yellowish in color, whereas those growing adjacent to pines in particular, and also near Douglas-fir and larch, show a marked increase in size and are a dark, healthy green color. Evidence suggests that the beneficial effects of these conifers is mycorrhizal. The mycorrhizal fungus *Boletus luteus* is prevalent beneath pine stands in this area.

1082. MacKenzie, A. M., and Christie, J. M.
1959. Studies of growth and yield. *In* Report on forest research for the year ended March 1958. Great Brit. Forest. Comm., pp. 79-80. London: H. M. Stationery Office.

1083. MacKenzie, J. M. D.
1945. The preference shown by birds for different species of trees in plantations. Forestry 19: 97-112.

As a result of counts made in about 120 plots, it was found that birds of the thicket type have strong preferences for nesting in certain tree species. Sitka spruce is the most popular species found. The suggestion is made that small plots of Sitka and Norway spruces planted in suitable places in plantations of other species giving bad nest sites will increase the number of birds, and examples are given of plots of this nature found to contain 40 to 50 nests per acre per annum. (From author's summary).

1084. MacLean, Colin D., and Hightree, Paul E.
1959. Forest statistics for Skagit and Whatcom Counties, Washington. USDA Forest Serv. Pacific Northwest Forest & Range Exp. Sta. Forest Surv. Rep. 133, 47 pp., illus.

1085. MacLean, J. D.
1945. Effect of heat on the properties and serviceability of wood. USDA Forest Serv. Forest Prod. Lab. R1471, 12 pp. plus tables and figures.

1086. McLeod, A. M., Yolton, L. A., Sanborn, W. A., and Phillips, R. S.
1945. A comparison of shearing strengths of glued joints at various grain directions as determined by four methods of test. USDA Forest Serv. Forest Prod. Lab. Rep. 1522, 9 pp. plus 2 tables and 15 figs.

1087. McMahon, F.
1945. Sitka spruce in Irish forestry. Irish Forest. 2(2): 66-71.

Sitka spruce was first introduced into Ireland as an ornamental tree about 80 years ago. Except for an experimental plot at Avondale, planted about 1905 or 1906, Sitka spruce appears not to have been used in plantations before 1909. Notes are given on its natural habitat, nursery treatment, and subsequent tending.

1088. McMinn, Howard E., and Maino, Evelyn.
1951. An illustrated manual of Pacific coast trees. 409 pp., illus. Berkeley, Los Angeles: Univ. Calif. Press.

1089. McNab, J.
1865. Remarks on some seedling coniferae raised from seed ripened in Britain. Bot. Soc. Trans. (Edinburgh) 8(2): 256-260.

Discusses arboretum specimens of Sitka spruce under the name *Abies menziesii*.

1090. McWilliams, H. G., Webster, L. T., McDaniel, Vern, and others.
1953. Cone collection, preparation and storage. *In* Reports of the Pacific Northwest Seeding and Planting Commission on various recommended reforestation practices and techniques. Western Forest. Conserv. Ass., pp. 15-20.

1091. Madison, Robert W.
1959. Growth and survival of a Sitka spruce plantation in coastal Oregon. USDA Forest Serv. Pacific Northwest Forest & Range Exp. Sta. Res. Note 178, 6 pp., illus.

A report on the first 8 years of height growth and survival of Sitka spruce. Total survival for the first eight growing seasons was 80.5 percent. The chief cause of early death was smothering by debris and soil movement, but from 1953 onward competition from vegetation caused most mortality. Planting larger stock to give further initial height advantage is recommended.

1092. _____ and Freed, Virgil H.
1962. Basal treatments for control of salmonberry. Weeds 10(3): 247-248.

Salmonberry (*Rubus spectabilis* Pursh.), a strong competitor of Sitka spruce seedlings, was basally treated in western Oregon during the dormant season and at bud bursting in April, using a 1:1 mixture 2,4-D and 2,4,5-T. January applications gave generally poorer results than those in March and

April. March and April applications produced 100-percent defoliation and kill for all treatments, with only erratic exceptions. Diesel oil alone gave effective control only in April. Sprays containing 2-1/2 percent active ingredients gave as good results as those containing 5 percent.

1093. _____ and Ruth, Robert H.
1962. Basal spraying of red alder. Weeds 10(4): 324-325.

Red alder saplings overtopping Sitka spruce and western hemlock regeneration were readily killed with a basal spray of 2,4-D and 2,4,5-T in diesel oil.

1094. Makins, F. K.
1942. Replanting softwoods. Quart. J. Forest. 36: 70-75.

Calculations based on yield from stands planted on sites of various quality classes show that, under British conditions, Douglas-fir, Sitka spruce, and European larch may be expected to yield higher rates of compound interest than other conifers. Yield tables for various species and quality classes are presented.

1095. Maksymov, Von J. K.
1965. Die Überwinterung des Lärchenblasenfu es *Taeniothrips laricivorus* Kratochvíl und Farský. [Overwintering of the larchthrips *Taeniothrips laricivorus* Krat. and Far.] Mitt. Schweiz Anst. Forstl. Versuchswesen 41(1): 3-18, illus. [In German. English summary.]

The female overwinters on Sitka spruce.

1096. Malcom, D. C.
1967. Environmental factors in the growth of Sitka spruce. *In* Report on forest research for the year ended March 1966. Great Brit. Forest. Comm., pp. 152-153. London: H. M. Stationery Office.

Reports on a project to determine the effect of combinations of locality factors. The project is in the development stage, but early results indicate that there is a relationship between locality factors and productivity.

1097. Manson, Marsdon.
1903. Forest advance over glaciated areas in Alaska and British Columbia. Forest Quart. 1(3): 94-96 plus 1 plate.

Describes plant succession following glacial retreat of Mendenhall Glacier, Alaska.

1098. Markwardt, L. J.
1930. Comparative strength properties of woods grown in the United States. U.S. Dep. Agr. Tech. Bull. 158, 38 pp.

1099. _____
1931. The distribution and the mechanical properties of Alaska woods. U.S. Dep. Agr. Tech. Bull. 226, 80 pp., illus.

1100. _____
1941. Aircraft woods: their properties, selection, and characteristics. USDA Forest Prod. Lab. Rep. 1079, 51 pp. (Reprint from Nat. Adv. Comm. Aeron. Rep. 354.)

Describes the important characteristics of many woods for aircraft construction, including Sitka spruce.

1101. _____ and Wilson, T. R. C.
1935. Strength and related properties of woods grown in the United States. U.S. Dep. Agr. Tech. Bull. 479, 99 pp., illus.

1102. Martin, Arthur James.
1951. Studies on the holocellulose of Sitka spruce: methylation of spruce holocellulose. 24 pp. (M. S. thesis on file at Univ. Brit. Columbia.)

1103. Maser, Chris.
1967. Black bear damage to Douglas-fir in Oregon. Murrelet 48(2): 34-38.

Reports that Sitka spruce is occasionally damaged along the coast.

1104. Matthews, A. F., Mitchell, A. F., and Faulkner, R.
1961. Forest genetics: selection of plus trees. *In* Report on forest research for the year ended March 1960. Great Brit. Forest. Comm., pp. 54-59. London: H. M. Stationery Office.

1105. Matthews, J. D.
1950. Genetics. *In* Report on forest research for the year ended March 1949. Great Brit. Forest. Comm., pp. 26-29. London: H. M. Stationery Office.

Individuals of Sitka spruce which appear to be able to throw off attack by *Neomyzaphis abietina* have been found in several localities. These have leaves with blunt and shouldered apices and a heavy construction; the leaf section is flat and the twigs are quite glabrous. Individuals of this type can often be spotted in a plantation by their dense, compact crowns, dense and flattened leaf arrangement, and bluish leaf coloration, and where *Neomyzaphis* is prevalent, by a sharp contrast in the intensity of infestation. The possibility that these trees are of hybrid origin is being followed up. Some notes are given on methods of grafting.

1106. _____
1952. Forest genetics: the progress of the general programme of improvement. *In* Report on forest research for the year ended March 1951. Great Brit. Forest. Comm., pp. 74-82. London: H. M. Stationery Office.

1107. _____
1955. Production of seed by forest trees in Britain. *In* Report on Forest research for the year ended March 1954. Great Brit. Forest. Comm., pp. 64-78. London: H. M. Stationery Office.

1108. _____
1962. Seed selection and tree breeding in Britain. Eighth Brit. Commonwealth Forest. Conf., Great Brit. Forest. Comm., 5 pp.

Describes the selection and management of seed production areas in Britain. With the expected improvement from seed produced in managed seed stands, the amount spent on seed can be doubled for fast-growing species such as Sitka spruce.

1109. _____
1963. Some applications of genetics and physiology in thinning. Forestry 36(2): 172-180.

The trend in Britain is toward heavier thinnings made less frequently, with careful choice of the trees retained. A table gives data on the range of maximum mean annual increment, duration of height growth, shade tolerance, needle retention, and age of first good seed crop for several species including Sitka spruce.

1110. Mayer-Krapoll, H.
1961. Beiträge zur forstdüngung: 1. Die düngung der Sitka. [Notes on forest manuring: 1. The manuring of Sitka spruce.] Forst- und Holzwirt. 16(18): 389-390. [In German.]

1111. _____
1964. Forst- düngungsversuche auf Ödland und grenzertragsböden. [Forest fertilizer trials on waste land and marginal land.] Phosphorsaure (Essen) 24(5/6): 213-226, illus. [In German.]

1112. Mayr, Heinrich.
1890. Die Waldungen von Nordamerika ihre Holzarten, deren Anbaufahigkeit und forstlicher wert fur Europa im Allgemeinen und Duetchland insbesonders. [The forests of North America, their tree species, their cultivation possibilities and general forest values for Europe.] 448 pp., illus. Munchen: Univ. Buchhandlung. [In German.]

1113. Meany, Edward S.
1918. Western spruce and the war. Wash. Hist. Quart. 9(4): 255-258.

1114. Megraw, R. A.
1967. A hydrodynamic particulate approach to pit membrane pore size distribution. Forest Prod. J. 17(11): 29-38, illus.

1115. Melchior, G. H.
1961. Versuche mit Gibberellinsäure and Waldbaum-Sämlingen und-Stecklingen. [The effect of gibberellic acid on seedlings and cuttings of forest trees.] Naturwiss. Rep. 48(9): 384, illus. [In German.]

Treatment of 3-year seedlings caused a reduction in leader length of Sitka spruce.

1116. Mentz.
1962. Sicherheit auf windefährdeten Boden Forstamt Barlohe. [Safety on sites with windthrow hazards in Barlohe District.] Allg. Forstz. 17(40): 636-637, 646, illus. [In German.]

Discusses windthrow associated with the heavy gales of 1962 in Schleswig-Holstein. On deep sands, carrying chiefly conifers, damage was severe. Norway spruce, Sitka spruce, and Scots pine suffered almost equally, but the larches and silver fir were largely, and hardwoods completely, windfirm on these sites.

1117. Mergen, F., and Thielges, B. A.
1967. Intraspecific variation in nuclear volume in four conifers. Evolution 21(4): 720-724.

Presents evidence of significant intraspecific variation in diploid nuclear volume, correlated with latitude of seed source, in *Picea glauca*, *P. sitchensis*, *Pinus sylvestris*, and *P. banksiana*. Evidence is based on filar micrometer measurements of nuclei from seedling roots of 12 geographic seed sources of each species, representing their full latitudinal range.

1118. Merker, E., and Klein-Krautheim, F.
1940. Der Riesenbastkafer an der Sitkafichte. [The giant bark-beetle (*Dendroctonus micans*) on Sitka spruce.] Allg. Forst- und Jagdzeit. 116: 255-261, illus. [In German.]

D. micans, a common pest of *Picea abies*, attacked *P. sitchensis* and a few *Pinus sylvestris*, but not *Picea abies*, at the Giessen Aboretum. The base of the tree and the roots at some distance from the trunk were generally attacked.

1119. Metcalf, Melvin E., and Hazard, John W.
1964. Forest statistics for northwest Oregon. Pacific Northwest Forest & Range Exp. Sta. USDA Forest Serv. Resource Bull. PNW-7, 38 pp.

1120. Meyer, Walter H.
1937. Yield of even-aged stands of Sitka spruce and western hemlock. U.S. Dep. Agr. Tech. Bull. 544, 86 pp., illus.

Includes a description of the Sitka spruce-western hemlock type, the silvical characteristics of the species, stand tables, and yield tables for mixed spruce-hemlock stands in Oregon, Washington, and Alaska.

1121. _____
1937. Yield tables for trees 6.6 inches and more in diameter in even-aged stands of Sitka spruce and western hemlock. (Supplement to Tech. Bull. 544. Yield of even-aged stands of Sitka spruce and western hemlock.) USDA Forest Serv. Pacific Northwest Forest & Range Exp. Sta., 8 pp.

1122. Miller, H. G., and Mackenzie, R. C.
1965. Research on Scottish forest and nursery soils. *In* Report on forest research for the year ended March 1964. Great Brit. Forest. Comm., pp. 83-86. London: H. M. Stationery Office.

1123. Milligan, Frederick H., and Davies, Raymond D.
1963. High-speed drying of western softwoods for exterior plywood. Forest. Prod. J. 13: 23-29, illus.

Describes an experimental veneer dryer. Douglas-fir 1/6-inch heartwood veneer was dried from 5- to 35-percent moisture content in 4.38 minutes at 300° F. and 3,000 feet per minute gas velocity, and in 0.95 minute at 550° and 9,000 feet per minute. Average surface temperatures of the veneer at 5-percent moisture content were 186° and 280°, respectively, and no loss of color, strength, or gluability occurred. Similar results were obtained for Douglas-fir sapwood, and for Sitka spruce, west coast hemlock, and west coast balsam fir.

1124. Minore, Don.
1966. Identification of rotten logs in the coastal forests of Oregon and Washington. USDA Forest Serv. Pacific Northwest Forest & Range Exp. Sta. 16 pp., illus.

Sitka spruce logs decay rather uniformly, and sound wood is rare when the outer portions are rotten and crumbly. An identification key is presented.

1125. Mitchell, A. F.
1965. The growth in early life of the leading shoot of some conifers. Forestry 38(1): 121-136.

1126. Mitchell, C., and Mitchison, I.
1950. Windblown Sitka spruce. Quart. J. Forest. 44(3): 149-150 plus 2 photos.

Stands of Sitka spruce in Kyloe Wood, Northumberland, were devastated by windthrow during gales in December 1949. The trees had been defoliated by "aphis" for several years in succession and this may have weakened their roots.

1127. Mocanu, V. G.
1955. Exoticele din parcul Calea-Codrului Ocolul silvic experimental-didactic Sinaia. [Trials of exotics in the Calea-Codru Park in the Sinaia experimental teaching circle.] Padurilor Rev. 70(6): 297-298. [In Rumanian.]

1128. Molnar, A. C.
1955. Province of British Columbia. Forest disease survey. Dep. Agr. Forest Insect & Dis. Surv. Annu. Rep. 1954: 128-135, illus.

1129. _____
1956. Province of British Columbia. Forest disease survey. Dep. Agr. Forest Insect & Dis. Surv. Annu. Rep. 1955: 102-106.

1130. _____ , Harris, J. W. E., and Ross, D. A.
1965. British Columbia region. Can. Dep. Forest., Forest Insect & Dis. Surv., pp. 93-109, illus.

1131. _____ , Harris, J. W. E., Ross, D. A., and Ginns, J. H.
1967. British Columbia region. Can. Dep. Forest., Forest Insect & Dis. Surv., pp. 108-124, illus.

Contains notes on several insect pests of Sitka spruce. Also lists the first record of western dwarf mistletoe on Sitka spruce in British Columbia, from Radley Park, Kitimat.

1132. Mooney, O. V.
1960. Some notes on shelterbelts in Irish coastal regions. Irish Forest. 17(2): 53-56.

Discusses choice of species, width, and spacing within and between rows. For peats, *Pinus contorta* is recommended, with *P. mugo* in mixtures only, and *Picea sitchensis* only for wider belts on better peats or moist soils.

1133. _____
1965. A background to silviculture in Irish forestry. Forestry 38(1): 8-19.

The writer traces the history of tree species and woodland in Ireland from early times down to the start of state forestry about 1906. He then considers the influence which the availability of land, the geology, the distribution of forest types, and the climate have had on silviculture since. He discusses the main species used, pure and in mixture, and notes that the type of ground available is the main limiting factor in the choice of species and that the tendency today is toward a very limited range of species in which *Picea sitchensis* and *Pinus contorta* have an important part to play. (Author's summary.)

1134. Moore, A. W.
1940. Wild animal damage to seed and seedlings on cutover Douglas-fir lands of Oregon and Washington. U.S. Dep. Agr. Tech. Bull. 706, 28 pp., illus.

In the fall of 1909 and following spring and fall, 4,000 acres were sown to Douglas-fir, Sitka spruce, and other species on a burned-over area on the Siuslaw National Forest, Oregon. An unpublished report stated, "Operation almost a complete failure."

1135. Moravets, F. L.
1943. The forest resource. *In* Forest resources of Oregon. Part I. Oregon State Board Forest. & Oregon State Coll. Sch. Forest., pp. 7-28, illus.

1136. _____
1949. Production of lumber in Oregon and Washington, 1869-1948. USDA Forest Serv. Pacific Northwest Forest & Range Exp. Sta. Forest Surv. Rep. 100, 12 pp.

1137. _____
1953. Forest statistics for Grays Harbor County, Washington. USDA Forest Serv. Pacific Northwest Forest & Range Exp. Sta. Forest Surv. Rep. 111, 24 pp., illus.

1138. Morris, William G.
1934. Forest fires in western Oregon and western Washington. Oreg. Hist. Quart. 35: 313-339.

Reports early conflagrations, several of which destroyed large acreages of Sitka spruce-western hemlock timber.

1139. _____
1936. The Tillamook burn--its area and timber volume. USDA Forest Serv. Pacific Northwest Forest & Range Exp. Sta. Note 18, 3 pp.

Shows volume of timber killed by species and ownership class. The total volume of Sitka spruce over 16 inches in diameter killed was 131 million board feet.

1140. Morton, B. R., and Lewis, R. G.
1917. Native trees of Canada. Can. Dep. Int. Forest. Br. Bull. 61, 233 pp., illus.

Gives range and description of Sitka spruce in Canada.

1141. Mosher, Milton M., and Lunnum, Knut.
1953. Trees of Washington. (Rev.) Wash. State Coll., Wash. Ext. Serv. Bull. 440, 40 pp., illus.

1142. Mounce, I.
1927. "Dote" disease of Sitka spruce (*Picea sitchensis* Carr.). Dominion Bot., Ottawa 1926: 20-24.

1143. Muenscher, W. C.
1941. Flora of Whatcom County. State of Washington; vascular plants. 139 pp., illus. Ithaca, New York: William A. Church Co.

1144. Muir, John.
1915. Travels in Alaska. 327 pp., illus. Boston and New York: Houghton Mifflin Co.

1145. Mulholland, F. D.
1937. The forest resources of British Columbia. Dep. Lands, Brit. Columbia Forest Serv., 153 pp., illus.

1146. Mulholland, Jack R.
1954. Changes in weight and strength of Sitka spruce associated with decay by a brown-rot fungus, *Poria monticola*. J. Forest Prod. Res. Soc. 4(6): 410-416, illus.

1147. Munger, Thornton T.
1945. A check list of the trees native to Oregon and Washington. USDA Forest Serv. Pacific Northwest Forest & Range Exp. Sta., 5 pp.

1148. _____
1945. Growth records of some permanent sample plots in Douglas-fir and spruce-hemlock. USDA Forest Serv. Pacific Northwest Forest & Range Exp. Sta., 6 pp.

1149. _____
1946. Windfall in relation to cutting. USDA Forest Serv. Pacific Northwest Forest & Range Exp. Sta. Res. Note 34: 11-12.

Windfall in Sitka spruce, western hemlock, and Douglas-fir stands on the Cascade Head Experimental Forest was several times greater in the

100-foot zone nearest the cutting edge than in the next 100-foot zone. Windfall was also heavy within 100 feet of a road. Right-of-way clearing through tall, dense timber should be of minimum width consistent with other considerations.

1150. _____
1946. Sample acres prove point; 17,523 board feet in 11 years. The Timberman 47(5): 48-50, illus.

Describes growth of spruce-hemlock plots in Oregon.

1151. _____
1947. The Wind River Arboretum from 1937 to 1946. USDA Forest Serv. Pacific Northwest Forest & Range Exp. Sta. Progr. Rep. 3, 21 pp. plus 8 figs.

1152. _____ and Greeley, W. B.
1927. Timber growing and logging practice in the Douglas-fir region. U.S. Dep. Agr. Dep. Bull. 1493, 42 pp., illus.

1153. _____ and Kachin, Theodore.
1949. Multiple-spur climbers for high pruning. J. Forest. 47: 375-377, illus.

1154. Munns, E. N.
1938. The distribution of important forest trees of the United States. U.S. Dep. Agr. Misc. Pub. 287, 176 pp., illus.

1155. Munro, Donald D.
1967. Ratios of standard cubic-foot volume to basal area for the commercial tree species of British Columbia. Fac. Forest., Univ. Brit. Columbia. 1 p. plus 24 tables.

Gives tables designed for use in compilation of variable-plot or "prism" cruises.

1156. Murphy, P. W.
1953. Soil faunal investigations. *In* Report on forest research for the year ended March 1952. Great Brit. Forest. Comm., pp. 123-126. London: H. M. Stationery Office.

Outlines the quantitative structure and vertical distribution of the fauna in natural heathland and cultivated heathland planted with Sitka spruce. The populations obtained from these habitats represent 570,000 and 835,000 organisms per square meter, respectively. In the natural heathland, this total is concentrated in the first 2-1/2 inches of the profile, whereas in the cultivated site, in addition to the litter fauna, there is a considerable percent in the raw-humus "sandwich" created in the cultivation process.

1157. Murray, J. S.
1954. Two diseases of spruce under investigation in Great Britain. Forestry 27(1): 54-62 plus 1 plate.

Descriptions are given of two apparently distinct diseases. One, termed "group dying," occurs mostly in Sitka spruce but sometimes in Norway spruce and is characterized by progressive death of the roots and a tendency for the trees to die in small groups in the stand. Trees between 20 and 30 years of age are usually attacked. The second disease is termed "top dying" and is confined to Norway spruce. (From author's summary.)

1158. _____
1955. Rusts of British forest trees. Great Brit. Forest. Comm. Booklet 4, 15 pp. plus 13 figs.

1159. _____ and Young, C. W. T.
1961. Group dying of conifers. Great Brit. Forest. Comm. Forest Rec. 46, 19 pp. plus 12 figs.

1160. Murray, James S.
1953. Group dying of spruce in Eire. Irish Forest. 10(2): 55-56.

Presents notes from Ireland on several examples of a disease, already under investigation in Great Britain, characterized by death of the root system and thinning of the crown, reduction in height increment, and unusually heavy cone production before death.

1161. _____
1955. *Rhizina inflata* associated with group dying of conifers in Britain. FAO Plant Protect. Bull. 4(1): 6.

Describes group dying of Sitka spruce and other tree species in west Britain and Ireland. A survey has shown a general association with the mealtime fires lit by workmen. The usually saprophytic *Rhizina* fruits vigorously on the charcoal, and fruit bodies are common on the ground in the groups. The majority of cases have also followed the first thinning, when such fires are lit. Mycelia have been traced to dark necrotic spots in the cortical tissues of dead tree roots. The gradual death of the roots is followed by a thinning of foliage and a slowing down of increment.

1162. Mustanoja, K. J., and Leaf, A. L.
1965. Forest fertilization research, 1957-64. Bot. Rev. 31(2): 151-246.

Gives a bibliography of forest fertilization research, containing many reports of work done with Sitka spruce.

1163. Nairn, Patrick.
1957. A second collection of wood specimens with 100 reproductions in colour. 206 pp., illus. London: Tothill Press.

1164. Nearn, W. T.
1955. Effect of water soluble extractives on the volumetric shrinkage and equilibrium moisture content of eleven tropical and domestic woods. Penn. Agr. Exp. Sta. (Forest. School Ser. 2) Bull. 598, 38 pp.

Describes the effect of extractives in certain species, including Sitka spruce, that show an abnormally low volumetric shrinkage for their specific

gravity class. Test methods and data are given in detail and the results discussed. It is concluded that the low volumetric shrinkage is a result of their low fiber-saturation point.

1165. Nedkvitne, Knut.
1964. En vurdering av dyrkningsverdien til utenlandske bartrearter pa Vestlandet og deira plass i landsdelen sitt skogbruk i framtida. [An estimation of the value of some exotic conifers for cultivation in western Norway and their place in the future forestry of the region.] Norsk Skogbruk 10 (13/14): 385-390, illus. [In Norwegian.]

Gives notes on the performance, pests, and diseases of several conifer species, including Sitka spruce.

1166. _____ and Troen, Ingvald.
1961. Nokre forsok med gjodsling og andre tiltak i Sitka-granplantingar pa lyngmark pa Vestlandet. [Trials of fertilizing and other measures in Sitka spruce plantations on heathland in Vestland.] Tidsskr. Skogbruk 69(1): 26-39, illus. [In Norwegian.]

1167. Nelson, Urban C.
1960. The forest-wildlife resources of Alaska. J. Forest. 58: 461-464, illus.

1168. Nemec, A.
1950. Hnojeni lesnich kultur: meliorace krnicich kultur a porostu. [The manuring of forest plantations: amelioration of checked plantations and stands.] Sb. vyzkumn Ust. Les. CSR 3, 437 pp. [In Czech. English summary.]

1169. Neustein, S. A.
1965. Direct sowing of Sitka spruce. *In* Report on forest research for the year ended March 1964. Great Brit. Forest. Comm., p. 26. London: H. M. Stationery Office.

1170. _____
1965. Investigations at sites of windthrow. *In* Report on forest research for the year ended March 1964. Great Brit. Forest. Comm., pp. 36-37. London: H. M. Stationery Office.

1171. _____
1965. Windthrow on the margins of various sizes of felling areas. *In* Report on forest research for the year ended March 1964. Great Brit. Forest. Comm., pp. 166-171, illus. London: H. M. Stationery Office.

1172. _____
1966. Direct sowing of Sitka spruce. *In* Report on forest research for the year ended March 1965. Great Brit. Forest. Comm., p. 33. London: H. M. Stationery Office.

1173. _____
1966. Trial plantations at high elevations. *In* Report on forest research for the year ended March 1965. Great Brit. Forest. Comm., pp. 169-172. London: H. M. Stationery Office.

1174. _____
1967. Mixtures of lodgepole pine and Sitka spruce. *In* Report on forest research for the year ended March 1967. Great Brit. Forest. Comm., p. 77. London: H. M. Stationery Office.

A survey of 91 stands of mixed lodgepole pine and Sitka spruce indicated that potential economic gains by an admixture of less than 50 percent spruce are not expected to be high.

1175. _____
1967. Slash disposal for regeneration. Fourteenth Congr. Int. Union Forest Res. Proc. Part IV, Sect. 23: 456-464.

Discusses alternative methods of slash disposal after clearcutting of planted Sitka spruce in Great Britain.

1176. _____
1967. Theoretical comparison of net discounted revenue of pure lodgepole pine and pure Sitka spruce on infertile peat. *In* Report on forest research for the year ended March 1966. Great Brit. Forest. Comm., pp. 37-38. London: H. M. Stationery Office.

Describes briefly an investigation to determine the economics of fertilizing Sitka spruce and lodgepole pine on infertile peat.

1177. Newlin, J. A., and Wilson, Thomas R. C.
1917. Mechanical properties of woods grown in the United States. U. S. Dep. Agr. Bull. 556, 28 pp., illus.

1178. Newport, Carl A., and Metcalf, Melvin E.
1965. Timber resource statistics for the Pacific Northwest as of January 1, 1963. Pacific Northwest Forest & Range Exp. Sta. USDA Forest Serv. Resource Bull. PNW-9, 38 pp.

1179. Nimmo, M.
1950. Planting experiments on lowland heaths. *In* Report on forest research for the year ended March 1949. Great Brit. Forest. Comm., pp. 48-50. London: H. M. Stationery Office.

1180. _____
1953. The 1945 broom and pine nursing experiments at Coldharbour, Wareham Forest, Dorset. *In* Report on forest research for the year ended March 1952. Great Brit. Forest. Comm., pp. 31-33 plus 2 photos. London: H. M. Stationery Office.

1181. Noble, Mary, de Tempe, J., and Neergaard, Paul.
1958. An annotated list of seed-borne diseases. Commonwealth Mycol. Inst. 159 pp.

The list is arranged under families of the hosts, with an index to pathogens, and indexes to common and Latin names of hosts, including Sitka spruce.

1182. Nobles, M. K.
1943. A contribution towards a clarification of the *Trametes serialis* complex. Can. J. Res. Rep. 21: 211-234 plus 4 plates.

The fungus frequently isolated from a destructive, brown cubical rot in Sitka spruce and Douglas-fir, and formerly referred to as *Trametes serialis*, Fries, has been connected with a fruit body collected on Sitka spruce in the Queen Charlotte Islands, B.C. By means of morphological, cultural, and interfertility studies it has been shown to be distinct from *Trametes serialis* and is described herewith under the name *Poria micropora* Overholts, n. sp. Similar studies of *Poria sequoiae* Bonar, *Polyporus palustris* Berk., and *Poria carbonicaa* Overholts, n. sp., all of which have been confused with *Trametes serialis* because of similarities between fruit bodies or cultures, have demonstrated the validity of each of the species and have provided criteria for their separation on the basis of cultural characters. (Author's summary.)

1183. Nokihara, Ezio; Tuttle, M. Jean; Felicetta, Vincent; and McCarthy, Joseph L.
1957. Lignin. VIII. Molecular weights of lignin sulfonates during delignification by bisulfite-sulfurous acid solutions. J. Amer. Chem. Soc. 79(16): 4495-4499, illus.

Discusses lignin sulfonates of *Tsuga heterophylla*, *Picea sitchensis*, and *Acer saccharum*.

1184. Nyholm, I.
1950. Anvendelse af flammekaster og hojtraffinerede petroleumsnaftaer til ukrudtsbekaempelse I planteskolerne. [Use of flamethrowers and highly refined petroleum oils for weed control in nurseries.] Dansk Skovforen. Tidsskr. 35(10): 528-536. [In Danish.]

1185. Oakleaf, Howard B.
1911. Wood-using industries of Oregon: with special reference to the properties and uses of Oregon woods. 46 pp. Portland: Oregon Conserv. Ass.

1186. O'Carroll, N.
1962. The progress of peatland afforestation in the republic of Ireland. Irish Forest. 19(1): 93-101.

1187. _____
1967. Fertilizers at planting time. Dep. Lands, Ireland, Forest. Div. Forest Res. Rev. 1957/64: 27-31.

1188. _____
1967. Season and time of planting. Dep. Lands, Ireland, Forest. Div. Forest Res. Rev. 1957/64: 31-32.

1189. _____
1967. Early growth of conifers on machine-cutover peatland. Fourteenth IUFRO-Kongress Pap. (Munchen) 9 (sec. 23 no. 4): 471-482, illus.

1190. _____ and O'Muirgheasa, N.
1963. The estimation of heart rot in standing crops; a note. Irish Forest. 20(1): 16-17.

A limited investigation in 56-year Sitka spruce suggests that the presence of markedly swollen butts is not related to the presence of heart

rot, and that estimates of the percent of affected trees in a standing crop based on observations from recent thinnings are apt to be exaggerated. (From author's summary.)

1191. O'Driscoll, J.
1967. Provenance trials. Dep. Lands, Ireland, Forest. Div. Forest Res. Rev. 1957/64: 12-22.

Describes provenance trials with 10 Sitka spruce seed origins from Oregon to Alaska. At the end of the third growing season, average height ranged from 1.6 feet (Cordova, Alaska) to 3 feet (Sooke, Vancouver Island). Frost hardiness of various provenances is discussed.

1192. Oedekoven, Karl.
1957. European experiences with Douglas and other conifers from western North America. Irish Forest. 15(1): 12-31.

Species discussed are Douglas-fir, western hemlock, western redcedar, and Sitka spruce.

1193. Øglaend, I.
1963. Rotrate pa Sitka. [Root rot of Sitka spruce.] Norsk Skogbruk 9(21): 616. [In Norwegian.]

1194. Øglaend, Ingar.
1961. Planter i plastpose. [Plants in plastic bags.] Norsk Skogbruk 7(19): 655. [In Norwegian.]

Sitka spruce planting stock (2 + 1) sealed in plastic bags in April and kept in shade were in good condition a month later. Those kept in perforated bags were in poorer condition in May. Spruce from the perforated bags transferred to sound bags in May and kept till June were damaged by mold, and some were dead when the bags were opened.

1195. Ohnesorge, B.
1959. Die Massenvermehrung der Sitkalaus in Nordwestdeutschland. [The outbreak of *Liosomaphis* (*Neomyzaphis*) *abietina* in northwest Germany.] Forstarchiv 30(4/5): 73-78, illus. [In German.]

1196. _____
1961. Wann sind Schäden durch die Sitkalaus zu erwarten? [When must we expect outbreaks of *Liosomaphis abietina*?] Allg. Forstz. 16(27/28): 408-410, illus. [In German.]

1197. Oksbjerg, E.
1952. Saltnedslag, en klimatisk faktor. [Salt deposition, a climatic factor.] Dansk Skovforen. Tidsskr. 37(8): 375-389. [In Danish.]

1198. _____
1960. Nogle iagttagelser over rodfordaerverangreb på Sitkagran i en midt- og en vestjydsk plantage. [Some observations regarding *Fomes annosus* attacks on Sitka spruce in plantations in central and western Jutland.] Dansk Skovforen. Tidsskr. 45(9): 345-372. [In Danish. English summary.]

1199. _____
1965. Tre nåletraearter i Midtjylland. [Three conifer species in mid-Jutland.] Hedeselsk. Tidsskr. 86(6): 113-128, illus. [In Danish.]

1200. _____
1965. Tre nåletraearters forhold. [Light relations of three conifers.] Hedeselsk. Tidsskr. 86(16): 367-374, illus. [In Danish.]

1201. _____
1966. Tre nåletraearters skudvaekst og frostfølsomhed. [The shoot growth and susceptibility to frost of three conifers.] Hedeselsk. Tidsskr. 87(13): 359-371, illus. [In Danish.]

1202. _____ and West-Nielsen, G.
1953. Om rodfordoerverangreb. [Damage to spruce by *Fomes annosus*.] Hedeselsk. Tidsskr. 74(15): 319-334, illus. (In Danish.]

1203. Oliver, Frank.
1966. Early thinnings of Sitka spruce. Scot. Forest. 20(2): 104-108.

1204. O'Muirgheasa, Niall.
1964. The pattern of annual growth in basal area of Sitka spruce, Norway spruce, and *Pinus contorta* in Ireland. Irish Forest. 21(2): 63-73.

1205. _____
1967. Inventory; census of woodlands, 1958/59; census extracts; volume sampling survey extracts. Dep. Lands, Ireland. Forest. Div. Forest Res. Rev. 1957/64: 83-114.

1206. Oosting, Henry J.
1956. The study of plant communities; and introduction to plant ecology. Ed. 2, 440 pp., illus. San Francisco: W. H. Freeman Co.

Describes briefly the tree associates of Sitka spruce throughout its natural range.

1207. Opperman, A.
1922. Sitkagranens vaekst i Danmark. [The Sitka spruce in Denmark.] Forstl. Forsogsv. Danmark. (Copenhagen) 6: 361-374, illus. [In Danish. English summary.]

Sitka spruce was introduced into Denmark about the same time as Douglas-fir, but it was rarely planted before 1890. In suitable spots growth rate is good, but in others, root rot, frost, and wind have caused damage. The species is now found in plantations throughout the country, and experience will eventually determine its place in Danish forestry. Information on growth rate and health is given.

1208. _____
1929. Racer af Douglasie og Sitkagran. [Races of Douglas-fir and Sitka spruce.] Saertryk af det Forstl. Forsøgsv. Danmark. beretning no. 90: 85-178. [In Danish. English summary.]

Describes provenance experiments with Douglas-fir and Sitka spruce from North America.

1209. Oregon Woodland Publication Council.
1963. Woodland handbook for the Pacific Northwest. 422 pp., illus. Coop. Ext. Serv. Corvallis: Oregon State Univ.

1210. Orloci, Laszlo.
1961. Forest types of the western hemlock zone. 206 pp., illus. (M.S. thesis on file at Univ. Brit. Columbia.)

Presents an ecosystem classification of the forest stands of the coastal western hemlock zone. Sitka spruce is shown to be an inhabitant of the wet edaphic habitats.

1211. _____
1964. Vegetational and environmental variations in the ecosystems of the coastal western hemlock zone. 204 pp., illus. (Ph.D. thesis on file at Univ. Brit. Columbia.)

1212. _____
1965. The coastal western-hemlock zone on the southwestern British Columbia mainland, vegetation-environmental patterns and ecosystem classification. *In* Ecology of western North America, V. J. Krajina [ed.], vol. 1, pp. 18-34. Univ. Brit. Columbia, Dep. Bot.

1213. Orr, P. W.
1963. Windthrown timber survey in the Pacific Northwest, 1962. USDA Forest Serv. Pacific Northwest Reg., 22 pp., illus.

The October 12, 1962, storm blew down an estimated 11.19 billion board feet of timber in Oregon and Washington including a considerable volume of Sitka spruce.

1214. _____
1966. Forest insect conditions in the various regions. Oregon and Washington. *In* Forest insect conditions in the United States, 1965, pp. 7-12, illus. USDA Forest Serv.

1215. _____, Pettinger, L. S., and Dolph, R. E.
1966. Forest insect conditions in the Pacific Northwest during 1965. USDA Forest Serv. Pacific Northwest Reg., 70 pp., illus.

Similar reports have been issued annually by the Insect Control Branch since 1962 and by the Pacific Northwest Forest and Range Experiment Station since about 1956. Earlier reports were by the Bureau of Entomology and Plant Quarantine.

1216. Osgood, Wilfred H.
1901. Natural history of the Queen Charlotte Islands, British Columbia. Natural history of the Cook Inlet Region, Alaska. U.S. Dep. Agr. Div. Biol. Surv., North Amer. Fauna 21, 87 pp., illus.

1217. Osmaston, F. C.
1955. Thoughts on yield tables. Forestry 28(2): 117-124.

Examines the recently published Forestry Commission Record, "Revised Yield Tables for Conifers in Great Britain," and shows how the standing volume, basal area, numbers of trees, and mean quartergirth vary with the mean top height, irrespective of age and quality class. By analogy with the Indian Forest Record, "Multiple Yield Tables for Deodar (*Cedrus deodara*)," he concludes that treatment does not materially affect this relationship. A modified yield table for Sitka spruce based on mean top height only is given. (From author's summary.)

1218. Ostrom, Carl E.
1960. Potentialities for improving forest growth. *In* Southern forest soils. Eighth Annual Forestry Symposium Proc., pp. 120-132, illus. Baton Rouge: Louisiana State Univ. Press.

Coastal Sitka spruce-western hemlock forests are second only to the coastal redwood type in northern California in natural timber production rates in the United States.

1219. Ouellette, G. B., and Magasi, L. P.
1966. *Lophomerum*, a new genus of Hypodermataceae. Mycology 58(2): 275-280.

Describes *Lophomerum septatum* sp. from needles of Sitka spruce.

1220. Ovington, J. D.
1953. Studies of the development of woodland conditions under different trees. 1. Soils pH. J. Ecol. 41(1): 13-34, illus.

1221. _____ and Madgwick, H. A. I.
1957. Afforestation and soil reaction. J. Soil Sci. 8(1): 141-149, illus.

Describes a study of the pH relationships between the soil, litter, and tree leaves at 10 experimental areas from 17 to 50 years after planting. At each of these areas a number of different tree species has been established, including Sitka spruce.

1222. Owen, T. H.
1954. Observations on the monthly litter-fall and nutrient content of Sitka spruce litter. Forestry 27(1): 7-15, illus.

The monthly needle-litter deposition in a 30-year-old Sitka spruce plantation was recorded over 2 years and the litter samples were analyzed. Seasonal variation was found both in the amount and in the nutrient content of the litter-fall. Most fell in late autumn and spring, least from June to September. The Ca content increased from May to November, while N and the other minerals decreased over the same period. Average total annual litter-fall was 1,832 pounds per acre; average nutrient contents, expressed as percent dry weight: Ca, 0.366; N, 1.085; K, 0.26; P, 0.24; and ash, 3.35. In comparison with results recorded in Europe and America for other conifers, the Ca content of the litter is low, but since the total amount of litter deposited annually is small, and the content of other minerals is relatively high, it is suggested that pure Sitka spruce plantations may not necessarily lead to soil deterioration. (From author's summary.)

1223. Owens, Charles E.
1936. Studies on the wood-rotting fungus *Fomes pini*. I. Variations in morphology and growth habit. Amer. J. Bot. 23: 144-149.

Discusses several tree species including Sitka spruce.

1224. Pacific Lumber Inspection Bureau, Inc.
1950. Export R. List. Grading and dressing rules, Douglas-fir, Pacific coast hemlock, Sitka spruce and western redcedar lumber. Seattle, Wash., 130 pp.

1225. Packman, D. F., and Laidlaw, R. A.
1966. Pulping of British grown softwoods. Part III. Variation in the pulping properties of Sitka spruce (*Picea sitchensis*). Holzforschung 20(5): 155-159.

Describes pulping properties of wood samples from stands 33 and 40 years old on the east and west coasts of Scotland. Mean fiber length was greater in high-density samples, and properties of pulp made by sulfite, kraft, and mechanical processes were related to density and fiber length.

1226. _____ and Orsler, R. J.
1964. Sulphite pulping of British-grown softwoods. I. Two-stage cooking of Sitka spruce. Holzforschung 18(6): 179-183, illus.

1227. Panshin, A. J., DeZeeuw, Carl, and Brown, H. P.
1964. Textbook of wood technology. Ed. 2, vol. 1, 643 pp., illus. New York: McGraw-Hill Book Co.

Contains information on structure, identification, uses, and properties of commercial woods of the United States including Sitka spruce.

1228. Parde, J.
1960. Contribution a l'étude de la productivite des reboisements de la région du plateau de Millevaches. [The productivity of the plantations on the Millevaches.] Rev. Forest. Franc. 12(8/9): 557-571, illus. [In French.]

1229. _____
1962. Aperçu sur la productivité des plantations resineuses en Bretagne. [The increment and yield of coniferous plantations in Brittany.] Rev. Forest. Franc. 14(5): 402-416. [In French.]

Deals mainly with the growth and yield of tree species that have passed the experimental stage, including Sitka spruce.

1230. Parker, R. E.
1957. Some problems arising in the afforestation of peat-land in northern Ireland. Irish Forest. 14(2): 118-121.

Describes the need for work on a vegetation classification and site-evaluation scheme, on treatments to prevent or overcome early check in Sitka spruce on *Calluna* sites, and on the effect of *Sphagnum* on trees, especially in stands opened up by thinning.

1231. _____
1962. The problems of peatland forestry. Irish Forest. 19(1): 3-14, illus.

Describes peatlands and problems encountered in establishing and growing timber on them in Ireland. On many sites Sitka spruce passes into a state of check a few years after planting. This condition is attributed to nitrogen starvation due to unsuccessful competition with *Calluna*.

1232. _____
1962. Factors limiting tree growth on peat soils. An investigation into the nutrient status of two peatland plantations. Irish Forest. 19(1): 60-81, illus.

Foliage analysis of two representative Sitka spruce plantations in northern Ireland led to a firm diagnosis of nitrogen deficiencies and a less firm diagnosis of phosphorous and potassium deficiencies. Tree and soil nutrient relationships are discussed.

1233. Parkin, K. F.
1957. Afforestation of peat-lands in northern Ireland. Irish Forest. 14(2): 111-117.

1234. Parlatore, P.
1868. *Picea menziesii*. *In* Prodromus septematis naturalis regni vegetabilis, A. P. de Candolle and A. de Candolle [eds.], [One of the seven leaders in vegetation.] Vol. 16, part 2, pp. 418-419. Paris. [In Latin.]

1235. Paton, J. M., and Hearmon, R. F. S.
1957. Effect of exposure to Gamma-rays on the hygroscopicity of Sitka spruce wood. Nature 180(4587): 651, illus.

Hygroscopicity (and possibly other physical properties) of the wood appears to be affected only by very heavy doses of radiation; at less than about 10^7 rad, the effect is negligible. In connection with insect control, doses not exceeding 60,000 rad and often considerably less have been mentioned. It is concluded that such low doses are unlikely to have any significant physical effect on the wood itself.

1236. Patric, J. H.
1966. Rainfall interception by mature coniferous forests of southeast Alaska. Soil & Water Conserv. 21(6): 229-231, illus.

Rainfall interception loss was measured in a mature stand of western hemlock-Sitka spruce. Interception loss of about 25 percent of the annual rainfall must be accounted for in the forest water budget of southeast Alaska.

1237. _____
1967. Frost depth in forest soils near Juneau, Alaska. Pacific Northwest Forest & Range Exp. Sta. USDA Forest Serv. Res. Note PNW-60, 7 pp., illus.

Describes frost penetration beneath a mature Sitka spruce-western hemlock forest, on clearcut areas, and on a logging road.

1238. Patscheke, G., and Kerner, G.
1963. Der gerbstoffgehalt von Sitkafichtenrinde. [The tannin content of Sitka spruce bark.] Soz. Forstwiss. (Berlin) 13(11): 328-330, illus. [In German.]

Analytical data are tabulated for two dominant and two suppressed stems to show differences in tannin content with height in the stem and with bark thickness. The mean content of single stems varied from 16.5 to 22.6 percent. The yield of dry substance from bark is estimated at 7 to 9 kilograms for the smallest second-class stem and 20 to 26 kilograms for the largest first-class stem. It is concluded that European-grown Sitka spruce constitutes a useful tannin source worth investigation by the leather industry.

1239. Paul, Benson H.
1963. The application of silviculture in controlling the specific gravity of wood. U.S. Dep. Agr. Tech. Bull. 1288, 97 pp., illus.

A table relates specific gravity to rings per inch. Data show that the best Sitka spruce from the standpoint of strength has a growth rate of 11 rings or more per inch.

1240. Paul, Frances.
1954. Spruce root basketry of the Alaska Tlingit. U.S. Dep. Int. Bur. Indian Aff. Indian Handcrafts 8, 80 pp., illus.

1241. Pawsey, R. G., and Gladman, R. J.
1965. Decay in standing conifers developing from extraction damage. Great Brit. Forest. Comm. Forest Rec. 54, 25 pp., illus.

1242. Peace, T. R.
1954. The control and avoidance of forest tree diseases. *In* Report on forest research for the year ended March 1953. Great Brit. Forest. Comm., pp. 62-70, illus. London: H. M. Stationery Office.

1243. _____
1962. Pathology of trees and shrubs with special reference to Britain. 753 pp., illus., plus 16 plates. London: Oxford Univ. Press.

The author devotes one chapter to diseases of spruce, including Sitka spruce (Chapter 23, pp. 307-317).

1244. _____ and Loughborough, H. L.
1949. Dying of groups of Sitka spruce. J. Forest. Comm. 20: 201-202.

1245. Pearson, F. G. O.
1963. Home-grown timber for cable drum manufacture. Timber Trades J. Annu. Spec. Issue, pp. 141-142, illus.

Includes data on the grades and dimensions of timber sawn from thinnings of 6-inch minimum top diameter. Species include Sitka spruce. Suitability for cable drum manufacture and condition after 2 years' service are discussed.

1246. Peattie, Donald Culross.
1953. A natural history of western trees. 751 pp., illus. Boston: Houghton Mifflin Co.

1247. Peavy, George W.
1929. Oregon's commercial forests. Oreg. State Board Forest. Bull. 2, 94 pp., illus.

1248. Peck, Edward C.
1933. Specific gravity and related properties of softwood lumber. U.S. Dep. Agr. Tech. Bull. 343, 24 pp., illus.

1249. _____
1957. Bending solid wood to form. U.S. Dep. Agr. Handbook 125, 37 pp., illus.

Endwise-compressibility values are given for 12 woods including Sitka spruce. The low value for Sitka spruce indicates that it is unsuited for bending.

1250. Peck, Morton E.
1919. Study of a section of the Oregon coast flora. Iowa Acad. Sci. Proc. 26: 337-362.

Covers the area from Yaquina Head to Yachats River.

1251. _____
1920. The vegetation of Cape Blanco. Iowa Acad. Sci. Proc. 27: 85-89.

1252. Peck, Morton Eaton.
1961. A manual of the higher plants of Oregon. Ed. 2, 936 pp., illus. Binfords & Mort.

1253. Penhallow, D. P.
1896. The generic characters of the North American Taxaceae and Coniferae. Roy. Soc. Can. Proc. and Trans. ser. 2, vol. 2, sect. 5, pp. 33-57, illus.

1254. _____
1907. A manual of the North American gymnosperms, exclusive of the Cycadales but together with certain exotic species. 374 pp. plus 55 plates. Boston: Ginn & Co., the Athenaeum Press.

1255. Perry, R. S.
1941. Sitka spruce. Emp. Forest. J. 20: 171-173.

Deals briefly with the natural distribution of Sitka spruce, the valuable properties and characteristics of its wood, and its many uses.

1256. Peters, William Harrison.
1936. In the forests of the Olympics. Amer. Forests 42(4): 170-176.

Describes the forest in the central range of the Olympic Mountains including Sitka spruce.

1257. Petersen, B. Beier.
1952. *Hylesinus micans* artens udbredelse og en oversigt over dens optraeden i Danmark. [*Dendroctonus micans*, its geographical distribution and a survey of its occurrence in Denmark.] Dansk Skovforen. Tidsskr. 37(6): 299-322, illus. [In Danish. English summary.]

1258. Petersen, Broder Beier.
1955. Hylobius-bekaempelse: forsøg med DDT, parathion og blyarsenat. [Control of *Hylobius* (*abietis*): Trials with DDT, parathion and Pb arsenate.] Dansk Skovforen. Tidsskr. 40(5): 200-215, illus. [In Danish. English summary.]

In field experiments, spraying young spruce with solutions containing 1 percent active DDT or 0.2 percent active parathion, or dipping the plants (top and roots, or top only) in DDT, gave good control.

1259. Peterson, C. A., and Cowling, E. G.
1963. Resistance of extractive-free coniferous woods to decay by white-rot fungi. (Abstr.) Phytopathology 53(3): 351.

No significant decrease in resistance to decay by *Polyporus* (*Polystictus*) *versicolor* and *P. anceps* resulted from extraction of wafers of Sitka spruce heartwood with ether, acetone, a one-half mixture (by volume) of ethanol/C_6H_6 and water, or with each of these solvents, successively in order of increasing polarity. Water extraction increased decay resistance. Impregnation of water-extracted wafers with solutions of 1 percent urea, 1 percent glucose, or both, decreased resistance, suggesting that water extraction had removed readily available nutrient materials essential to decay.

1260. Peterson, Roger S.
1964. Diseases of *Picea* (other than *P. abies*). *In* Diseases of widely planted forest trees, by Working Group on International Cooperation in Forest Disease Research, Section 24, Forest Protection, International Union of Forestry Research Organizations, pp. 38-51. FAO/IUFRO Symp. Int. Dangerous Forest Dis. & Insects (Oxford) July 20-30, 1964.

1261. Petrie, S. M., and MacKay, A.
1948. Seed-beds and the heat wave. Scot. Forest. 1(3/4): 30-31.

Seed sown in Argyll in the last week of May 1946 made normal growth until the beginning of August. About mid-August it was noted that seedlings were turning brown and then breaking off at the soil surface. It was concluded that the damage was due to heat; the crystalline particles of grit covering the beds, having been raised to a very high temperature, scorched the seedling stems. The severity of damage to species was in the following order: Japanese larch, Sitka spruce, Scots pine, Norway spruce, Douglas-fir.

1262. Phillips, D. H.
1964. Forest pathology. *In* Report on forest research for the year ended March 1963. Great Brit. Forest. Comm., pp. 56-60. London: H. M. Stationery Office.

Describes heavy infection of Sitka spruce seedlings in a nursery by gray mold (*Botrytis cinerea*).

1263. Phillips, E. W. J.
1941. The inclination of the fibrils in the cell wall and its relation to the compression strength of timber. Emp. Forest. J. 20: 74-78.

As part of an investigation into the relation between anatomical structure and the maximum crushing strength of British-grown Sitka spruce, the influence of the degree of inclination of the spirally arranged fibrils of the middle layer in the secondary tracheid wall was examined. A satisfactory method of determining the fibril angle from the slope of the ray pit apertures is described. The normal variation in fibril angle within the tree was determined and the causes of this are discussed.

1264. _____
1948. Identification of softwoods by their microscopic structure. Forest Prod. Res. Lab. Bull. 22, 56 pp., illus. (Reprinted 1963.)

1265. _____
1963. Timber improvement by tree selection and breeding. World Consultation Forest Genetics Tree Improvement Proc. (Stockholm), Sect. 7, pp. 1-5.

Describes methods developed for the study of timber features in plus trees of British-grown Sitka spruce, with special reference to density, fiber length, and spiral grain.

1266. _____, Adams, E. H., and Hearmon, R. F. S.
1962. The measurement of density variation within the growth rings in thin sections of wood, using Beta particles. J. Inst. Wood Sci. (London) 10, pp. 11-28, illus.

Discusses the development of a method using β-particles from C^{14}.

1267. _____ and Patterson, D. G.
1965. Two-stage windthrow in Sitka spruce. Quart. J. Forest. 59(4): 322-326, illus.

Investigation of brittle windthrow fractures following an easterly gale in a stand of Sitka spruce growing on a Devonshire hillside showed that the stems had broken off at compression failures induced by a westerly gale 2 years earlier, following the cutting of a roadway, which increased the exposure. The "first stage" damage had become protected by wound tissue and rapidly developed compression wood, giving rise to well-marked stem swellings which presumably saved some stems from second and final damage when the rest were broken. The term "compression swelling" is suggested for this defect. (Authors' summary.)

1268. Pillai, Ambuja.
1964. Root apical organization in gymnosperms--some conifers. Torrey Bot. Club Bull. 91(1): 1-13, illus.

Describes the root apical organization of several conifers, including Sitka spruce.

1269. Pillow, Maxon Y.
1949. Studies of compression failures and then detection in ladder rails. USDA Forest Serv., Forest Prod. Lab. Rep. D-1733, 10 pp. plus photos.

Includes Sitka spruce.

1270. Pillsbury, R. W.
1962. The wet coastal forest of British Columbia. (Abstr.) Ecol. Soc. Amer. Bull. 43(3): 54.

1271. Pinchin, R. D.
1951. Nursery extension experiments at Radnor Forest. *In* Report on forest research for the year ended March 1950. Great Brit. Forest. Comm., pp. 24-27. London: H. M. Stationery Office.

Summarizes the followup, in the forest, of experiments made in 1921-27 to test the effects of different densities and methods of sowing seed and grading of seedlings and transplants, for Douglas-fir, Norway and Sitka spruce, and European larch. Results were mainly negative, except that grading of transplants (unlike grading of seedlings at time of lining out) into good plants and culls gave positive results: The mean height for all good plants at the end of the eighth growing season was 60.6 inches compared with 48 inches for the culls.

1272. Pinchot, Gifford.
1907. Sitka spruce. U.S. Dep. Agr. Forest Serv. Silvical Leafl. 6, 4 pp.

1273. Piper, Charles V.
1906. Flora of the State of Washington. U.S. Nat. Herb. Contrib., vol. 11, 637 pp., illus.

1274. _____ and Beattie, R. Kent.
1915. Flora of the northwest coast; including the area west of the summit of the Cascade Mountains, from the forty-ninth parallel south to the Calapooya Mountains on the south border of Lane County, Oregon. 418 pp. Lancaster, Pa.: New Era Printing Co.

1275. Place, I. C. M.
1950. The identification of spruce seedlings. Can. Forest. Br. Silvicult. Leafl. 40, 2 pp., illus.

The margins of the juvenile needles of red, black, and Sitka spruce are smooth, whereas those of white and Norway spruce are usually serrulate with fine teeth on each of the four corners of the needle.

1276. Platt, Rutherford.
1952. American trees; a book of discovery. 256 pp., illus. New York: Dodd, Mead & Co.

1277. Platt, Rutherford Hayes.
1965. The great American forest. 271 pp., illus. Englewood Cliffs, N. J.: Prentice-Hall.

1278. Plummer, Fred G.
1900. Mount Rainier Forest Reserve, Washington. In Twenty-first annual report 1899-1900, part 5, Forest Reserves. U.S. Geol. Surv., pp. 81-143, illus.

1279. Polge, Hubert.
1963. Contribution a l'étude de la qualité du bois des principales essences resineuses exotiques utilisee dans les reboisements Français. [The quality of wood of the principal exotic conifers used in French plantations.] Ann. de L'Ecole Nat. Des Eaux et Forêts 20(3): 401-469 plus 2 plates. [In French.]

A study of the physical, mechanical, and working properties of samples, from the Royal Arboretum, of several conifers, including Sitka spruce.

1280. Pomeroy, Kenneth B., and Dixon, Dorothy.
1966. These are the champs. Amer. Forests 72(5): 14-35, illus.

Lists the largest known Sitka spruce in the United States: located in Olympic National Park, Wash., it is 41 feet, 8 inches in circumference and 214 feet high, and has a 50-foot spread.

1281. _____ and Littlecott, Lorna C.
1967. The social register - 85 new champs. Amer. Forests 73(9): 28-33, illus.

The largest Sitka spruce recorded (as of 1967) is the "Helen Clapp Spruce," located near Forks, Wash. Circumference at breast height, 56.2 feet; height, 248 feet; spread, 88 feet.

1282. Prax, J. L., and Parde, J.
1964. Les resineux dans le nord- ouest de L'Herault. [Conifers in the northwest of Herault.] Rev. Forest Franc. 16(4): 286-301. [In French.]

Notes on sample plots of several exotics from western North America, including Sitka spruce.

1283. Prentice, R. M. (Compiler).
1962. Forest lepidoptera of Canada, recorded by the forest insect survey. Vol. 2. Nycteolidae, Notodontidae, Nodtuidae, Liparidae. Can. Dep. Forest., Forest Entomol. Pathol. Br. Bull. 128: 77-281, illus.

Includes available data on distribution, feeding type, relative abundance, and seasonal occurrence of insects attacking Sitka spruce.

1284. _____
1963. Forest lepidoptera of Canada, recorded by the forest insect survey. Vol. 3. Lasiocampidae, Thyatiridae, Drepanidae, Geometridae. Can. Dep. Forest., Forest Entomol. Pathol. Br. Pub. 1013: 282-543, illus.

1285. _____
1965. Forest lepidoptera of Canada, recorded by the forest insect survey. Vol. 4. Microlepidoptera. Can. Dep. Forest., Forest Entomol. Pathol. Br. Pub. 1142: 543-840, illus.

1286. Preston, Richard J., Jr.
1961. North American trees (exclusive of Mexico and tropical United States). Ed. 2, 395 pp., illus. Ames: Iowa State Univ. Press.

1287. Puchert, H.
1956. Die Sitka-fichte im ehemaligen land Braunschweig. [Sitka spruce in the former province of Brunswick.] Allg. Forstzeitschrift 45/46: 577-581. [In German.]

1288. Pyatt, D. G.
1966. The soil and windthrow survey of Newcastleton Forest, Roxburghshire. *In* Report on forest research for the year ended March 1965. Great Brit. Forest. Comm., pp. 204-206. London: H. M. Stationery Office.

1289. _____
1967. Planning and economics. *In* Report on forest research for the year ended March 1966. Great Brit. Forest. Comm., p. 79. London: H. M. Stationery Office.

1290. _____
1967. Soil survey for forestry purposes in upland Wales. Welsh Soils Discuss. Group Rep., pp. 110-119.

Freely drained brown earths and ochreous brown earths are suitable for Sitka spruce. Alluvial soil and mineral gley appear better for Norway than for Sitka spruce. Sitka is more suitable than Norway on ironpan soils, transition soils between ochreous and ironpan, and shallow and deep peaty gley soils, these being too exposed for Norway spruce. Except for deep peats, Sitka is preferred for most land over 1,000-foot elevation.

1291. Querengässer, F.
1953-54. Die grüne Douglasie (*Pseudotsuga taxifolia*, Douglas-fir, red fir) und ihre begleitholzarten. [The green Douglas-fir and its associated trees.] Deut. Dendrol. Ges. Mitt. 58: 127-141. [In German.]

1292. _____
1956. Was ist beim Anbau der Douglasie und Sitka-fichte zu berucksichtigen? [What is to be considered in the cultivation of Douglas-fir and Sitka spruce?] Allg. Forstzeitschrift 45/46: 586-589. [In German.]

1293. Raabe, Robert D.
1962. Host list of the root rot fungus, *Armillaria mellea*. Hilgardia 33(2): 25-88.

Host list includes Sitka spruce in England, Eire, Denmark, and the United States (Washington State).

1294. Radcliffe, Byron M.
1965. A theoretical evaluation of Hankinson's formula for modulus of elasticity of wood at an angle to the grain. Mich. Agr. Exp. Sta. Quart. Bull. 48(2): 286-295, illus.

1295. Radu, St.
1962. Duglasul, molidul de Sitka si alte specii in Ocolul silvic Anina. [Douglas-fir, Sitka spruce and some other species in the Anina Forest Region, Rumania.] Padurilor Rev. 77(2): 80-83, illus. [In Rumanian. English summary.]

Gives mean height and d.b.h. from experimental plantations, 43 to 63 years old, of *Pseudotsuga taxifolia*, *Abies balsamea*, *Picea glauca*, and *P. sitchensis*, with *P. abies*, *Larix decidua*, *Pinus sylvestris*, *Abies alba*, and *Fagus sylvatica* for purposes of comparison.

1296. Ragnarsson, H.
1964. Trjaskemmdir vorid 1963. [Damage to trees in spring 1963.] Ársrit Skógraektarf. Islands 1964: 25-27. [In Icelandic.]

Sitka spruce was particularly affected by a severe frost in early April after a long cold spell.

1297. Ram Reddy, M. A., and Last, F. T.
1961. Sitka seedling diseases. Rothamsted [England] Exp. Sta. Rep. 1960: 127-128.

1298. _____ and Last, F. T.
1962. Sitka seedling diseases. Rothamsted (England) Exp. Sta. Rep. 1961: 119.

Soils from five Forestry Commission nurseries were analyzed by a modified dilution-plate method, and fungus populations were compared. The two groups of fungi most often isolated from diseased Sitka spruce seedlings were rarely isolated from soil. *Cylindrocarpon radicicola* was the fungus most frequently isolated at Kennington Old and Ringwood nurseries; next was a group of *Pythium* spp. (*P. ultimum*, *P. irregulare*, and two new species).

1299. _____, Salt, G. A., and Last, F. T.
1964. Growth of *Picea sitchensis* in old forest nurseries. Ann. Appl. Biol. 54(3): 397-414 plus 1 plate, 2 figs., 24 graphs, 8 tables.

Partial sterilization of nursery soil reduced seedling losses attributed mainly to invasion by *Pythium* spp.

1300. Randall, Warren R.
1965. Manual of Oregon trees and shrubs. 234 pp., illus. Corvallis: Oregon State Univ. Book Stores.

1301. Rankin, W. H.
1918. Manual of tree diseases. 398 pp., illus. New York: Macmillan Co.

1302. Rapraeger, Harold A.
1952. Total height volume tables for western hemlock, Sitka spruce, and young growth Douglas-fir (based on 32-foot logs and on an

8-inch top). USDA Forest Serv. Pacific Northwest Forest & Range Exp. Sta. Res. Note 82, 6 pp.

Tables were developed by adjusting tree volumes in existing tables, a large sample of measured trees of each of the three species being analyzed to provide adjustment factors.

1303. Rasmussen, Axel.
1961. Hansted byplantage. [Hansted town plantations.] Dansk Skovforen. Tidsskr. 46(5): 208-224, illus. [In Danish.]

Discusses planting since 1950, aimed at providing shelter for the town and harbor in a district of northwest Jutland very much exposed to wind, where the soil is a moraine layer overlying limestone and covered by various depths of blown sand. Includes notes on the early development of various species tried, including Sitka spruce.

1304. Rasmussen, Edmund F.
1961. Dry kiln operators manual. U.S. Dep. Agr. Handbook 188, 197 pp., illus.

Gives detailed information on construction and operation of dry kilns. Proper control of drying conditions and handling of lumber are stressed. Drying schedules are given for many woods including Sitka spruce. Tabular values are given for specific gravity, electrical resistance, moisture content, and shrinkage.

1305. Rave, D.
1951. Zu den Untersuchungsergebnissen über die Sitka des Herrn Dr. Friedrich. [Results of Dr. Friedrich's researches on Sitka spruce.] Forst- und Holz. 6(3): 38-39. [In German.]

Author concludes that the high yields obtained from Sitka spruce in Germany outweigh the danger of loss from *Fomes annosus* attack.

1306. Rayner, M. C., and Levisohn, I.
1941. The mycorrhizal habit in relation to forestry. IV. Studies on mycorrhizal response in *Pinus* and other conifers. Forestry 15: 1-36.

Describes mycorrhizal and pseudomycorrhizal association in a number of conifers, observed during 10 years' intensive study of experimental sowings and plantings in an afforestation area in southwestern England. The species receiving special attention include Sitka spruce.

1307. Record, Samuel J.
1919. Identification of the economic woods of the United States; including a discussion of the structural and physical properties of wood. Ed. 2 (rev. and enlarged), 157 pp. plus 6 plates. New York: John Wiley & Sons; and London: Chapman & Hall, Ltd.

1308. _____
1934. Identification of the timbers of temperate North America, including anatomy and certain physical properties of wood. 196 pp., illus. New York: Wiley & Sons.

1309. _____ and Hess, Robert W.
1943. Timbers of the new world. 640 pp., illus. New Haven: Yale Univ. Press.

1310. Rediske, J. H.
1961. Chemical selectivity in woody plants. Hormology 3(2): 7-9.

Describes experiments made at the Weyerhaeuser Forestry Research Center to investigate the selectivity of weedkillers. Results are tabulated, giving comparative effects of different preparations on several tree and brush species including Sitka spruce.

1311. _____ and Johnson, Norman E.
1965. The absorption and translocation of the systemic insecticide Schradan in Sitka spruce and grand fir. Weyerhaeuser Timber Co. Weyerhaeuser Forest. Pap. 5, 9 pp., illus.

Schradan tagged with P^{32} was tested on seedlings grown in nutrient solutions in a controlled-environment chamber. Sixty parts per million Schradan in the nutrient solution was absorbed in greatest amounts in the current foliage after 16 days (3.5 parts per million in spruce) with old foliage, bark, and wood in decreasing order. Schradan applied to terminal buds was shown by autoradiographs to be absorbed and translocated down the main stem and into lateral branches.

1312. Rehder, A.
1949. Manual of cultivated trees and shrubs hardy in North America. Ed. 2 (rev. and enlarged), 996 pp., illus. New York: MacMillan Co.

1313. Rehder, Alfred.
1949. Bibliography of cultivated trees and shrubs hardy in the cooler temperate regions of the northern hemisphere. 825 pp. Jamaica Plain, Mass.: Arnold Arboretum, Harvard Univ.

Gives references to the sources of botanical names, valid names, and synonyms of Sitka spruce. (14 references.)

1314. Reinhold, M.
1953. Englische Ertragstafeln für Japanische Lärche, Douglasie und Sitkafichte. [British yield tables for Japanese larch, Douglas fir, and Sitka spruce.] Forstarchiv 24(11/12): 261-263, illus. [In German.]

Presents Forestry Commission yield tables recalculated in metric units with volume and height curves.

1315. Rendle, B. J.
1952. Strawberry mark in Sitka spruce lumber. *In* Selected government research reports, vol. 8, pp. 1-2, illus. London: H. M. Stationery Office.

Strawberry mark, a defect of Sitka spruce timber, is a reddish-brown patch, up to 1 by 1-1/2 inches in size, running radially through the wood. It is due to abnormal deposits of resin in the ray cells and does not always affect the wood structure, although in some cases the rays are greatly enlarged, thus reducing the strength of the wood. There may also be a slight deviation in grain.

1316. Rennie, P. J.
1951. Physico-chemical properties of forest soils. Imp. Forest. Inst. Rep. (Oxford) 1949/50: 9.

Chemical analysis of moorland soils from Allerston Forest, Yorkshire, has demonstrated a high concentration of nutrients in the surface peat, where Ca, P, and K contents are respectively 10, five, and two times as great as in the subsoil of lower calcareous grit. The leached layer is very deficient in nutrients. The nutrient content of the litter formed by Sitka spruce planted on this soil is much higher where the trees are growing well than where growth is poor--the figures for Ca were respectively 9 milligrams per gram litter and 2 milligrams per gram litter.

1317. _____
1951. Research into the physical and chemical properties of forest soils. *In* Report on forest research for the year ended March 1950. Great Brit. Forest. Comm., pp. 116-118. London: H. M. Stationery Office.

Failures of Sitka spruce on deep-plowed areas were fewer than on screefed plots. On screefed plots failures tended to be more common on areas formerly occupied by *Eriophorum* spp. Earlier flushing occurred on deep-plowed plots.

1318. _____
1953. Research into the physical and chemical properties of forest soils. *In* Report on forest research for the year ended March 1952. Great Brit. Forest. Comm., pp. 108-116. London: H. M. Stationery Office.

1319. _____
1958. Improvement of the timber productivity of heather moor. Quart. J. Forest. 52: 36-40, illus.

Three planting regimes--Sitka spruce, Sessile oak, and unplanted control--each with and without limestone, are combined factorially with three methods of cultivation. Early results show that on ploughed moor, limestone improves the growth of spruce and materially alters the moor vegetation by drastically increasing grasses at the expense of heather. (From author's summary.)

1320. Rheinheimer, G.
1961. Folgeschaden des extremen Sommers 1959 in den Wäldern der Länder Schleswig-Holstein und Hamburg. [Damage resulting from the extreme summer of 1959 in the forests of the Schleswig-Holstein and Hamburg regions.] Forstarchiv 32(4): 65-73, illus. [In German.]

First losses in 1959 were in new plantations, but by July mature plantations and pole crops had suffered serious loss. In spring 1960 serious damage was visible in mature stands of Norway and Sitka spruce, and in the southeast of the region, in beech also. Heavy salvage fellings were necessary in places. The greatest losses occurred on mineral soil of high organic content where the water table had sunk sharply, and on dune sand, where damage on stand margins was considerable, particularly near

the coast. Increased numbers of insect pests were observed in 1960. The causes of the damage were complex, depending much more on soil condition, site, and stand situation than on absolute temperature and amount of rainfall.

1321. Rhoads, Arthur S., Hedgcock, George G., Ellsworth, Bethel, and Hartley, Carl.
1918. Host relationships of the North American rusts, other than Gymnosporangiums, which attack conifers. Phytopathology 8(7): 309-352.

1322. Ricard, Louis.
1956. Un essai de plantation resineuse dans une tourbiere. [An experiment in planting conifers on a peat bog.] Rev. Forest Franc. 8(2): 102-107. [In French.]

Describes an adaptation of the planting methods developed by the United Kingdom Forestry Commission. Sitka spruce was planted along the edge of shallow drainage ditches. The upturned turfs (1 meter square) are lifted by hand, a seedling placed between them, and a third turf propped against the other two on the side away from the ditch. This results in a 3-meter spacing, and preliminary indications promise good survival and growth.

1323. Richards, E. G.
1957. Extractives from wood and bark. *In* Report on forest research for the year ended March 1957. Great Brit. Forest. Comm., p. 82. London: H. M. Stationery Office.

1324. _____
1957. Seasoning in the forest. *In* Report on forest research for the year ended March 1957. Great Brit. Forest. Comm., p. 83. London: H. M. Stationery Office.

1325. _____
1957. Utilization development. *In* Report on forest research for the year ended March 1957. Great Brit. Forest. Comm., pp. 91-94, illus. London: H. M. Stationery Office.

1326. Richardson, S. D.
1959. The effect of night temperature on tracheid size and wood density in conifers. Int. Ass. Wood Anat. News Bull. 2: 4.

Consists of an abstract of a paper prepared for the International Botanical Congress, Montreal. In seedlings of Douglas-fir, *Sequoia sempervirens*, and Sitka spruce grown under a range of different day and night temperatures, in a controlled environment, wood density and cell-wall thickness increased as temperature increased, but showed no consistent relation with day temperature or growth rate. Tracheid length increased as temperature increased, night or day. It is suggested that cell elongation is a relatively direct function of temperature, whereas cell-wall thickness is determined by net assimilation rate. A hypothesis based on observed changes in net assimilation rate with age is proposed to account for differences in density between so-called juvenile and adult wood.

1327. _____
1964. Studies on the physiology of xylem development. III: Effects of temperature, defoliation, and stem girdling on tracheid size in conifer seedlings. J. Inst. Wood Sci. 12, 3-11, illus.

It is concluded that tracheid length is influenced by temperature both directly and indirectly; but that increases in cell length associated with increasing light intensity are not explainable in terms of carbohydrate accumulation. The major determinants of lumen diameter are probably hormonal, but temperature can act directly within this framework. Cell-wall thickness is, to a large degree, influenced by carbohydrate availability but hormonal factors may also operate. (From author's summary.)

1328. _____ and Dinwoodie, J. M.
1960. Studies on the physiology of xylem development. I: The effect of night temperature on tracheid size and wood density in conifers. J. Inst. Wood Sci. 6, 3-13, illus.

1329. Richens, R. H.
1945. Forest tree breeding and genetics. Joint Pub. 8. Imp. Agr. Bur. [Penglais, Aberystwyth, Great Britain], 79 pp.

Contains a bibliography of literature on forest tree breeding from 1930 to 1945.

1330. Rieger, S., and DeMent, J. A.
1965. Cryorthods of the Cook Inlet-Susitna lowland, Alaska. Soil Sci. Soc. Amer. Proc. 29(4): 448-453.

In the vicinity of Kachemak Bay at the southern end of the study area, Sitka spruce is the dominant tree. Physical and chemical properties of cryorthods (Podzols) are described.

1331. Rieger, Samuel, and Wunderlich, R. Eugene.
1960. Soil survey and vegetation of northeastern Kodiak Island area, Alaska. USDA Soil Conserv. Serv. Soil Surv. Ser. 1956, no. 17, 46 pp., illus., with map in pocket.

1332. Rigg, G. B.
1917. Forest succession and rate of growth in sphagnum bogs. J. Forest. 15: 726-739.

Includes descriptions of forest succession on four bogs containing Sitka spruce, one in the Puget Sound region and three in Alaska.

1333. Rigg, George B.
1925. Some sphagnum bogs of the north Pacific coast of America. Ecology 6(3): 260-278, illus.

1334. _____
1937. Some raised bogs of southeastern Alaska with notes on flat bogs and muskegs. Amer. J. Bot. 24: 194-198.

Sitka spruce is one of five tree species growing on a raised bog near Juneau, Alaska. Development, plant succession, and ecology of this and other bogs in southeast Alaska are discussed.

1335. _____ and Harrar, E. S.
1931. The root systems of trees growing in sphagnum. Amer. J. Bot. 18(6): 391-397, illus.

Describes the character and distribution of conifer roots, including Sitka spruce, growing in bogs whose surface layer is sphagnum peat. Observations in all cases indicate excessive elongation of roots growing in peat soils.

1336. Rindt, Charles A., Woods, John B., Jr., and Schroeder, George H.
1953. Direct seeding of forest lands. *In* Reports of the Pacific Northwest Seeding and Planting Comm. on various recommended reforestation practices and techniques, pp. 21-35. Western Forest. Conserv. Ass., Portland, Oreg.

1337. Rishbeth, John.
1967. Control measures against *Fomes annosus* in Great Britain. Fourteenth IUFRO-Kongress Pap. (Munchen) 9 (sect. 24, no. 5): 299-306.

1338. Rivers, Claude F., and Crooke, Myles.
1962. Virus control of the sawfly (*Neodiprion sertifer* Geoff.). Fifth World Forest. Congr. Proc. (Seattle) 1960, 2 (sect. 3C): 951-952.

Describes small-scale trials in (a) a heavily infested shelterbelt of Scots pine and Sitka spruce, just over 7 feet high, in Norfolk, sprayed in mid-May at the third-instar stage, and (b) a mixed Scots pine-Sitka spruce stand in Scotland, 3 to 15 feet high, sprayed in May at stages from egg to second instar. In (a), thorough wetting with 200,000 polyhedra per milliliter, and in (b) mist-blowing with 1-1/2 gallons per acre containing 500,000 polyhedra per milliliter gave good control. In (a) the disease had spread in the following year to untreated or more lightly treated parts, causing almost complete mortality of sawflies.

1339. Robak, H.
1957. Sambandet mellom daglengden og avslutningen av den arlige vekstperioden hos en del nåletreslag av interesse for värt skogbruk. [The relation between day length and the end of the annual growth period in some conifers of interest to Norwegian Forestry.] Medd. Vestlandet. Forstl. Forsøkssta. 31: 62. [In Norwegian. English summary.]

To establish a 14-hour photoperiod during the summer, seeds were sown in a "shading box" (illustrated) from which light could be excluded; for comparison, seeds were sown in the open or in similar boxes either (1) uncovered or (2) covered with plexiglass. One-year seedlings of Sitka spruce of provenances from regions with a day length shorter than that in Norway during summer but longer than 14 hours, formed terminal buds earlier than controls. Frost-lifting affected the results, but otherwise the short-day treatment gave better wintering. Further experiments are planned.

1340. Robak, Håkon.
1950. Proveniensproblemet og vekstforedling av skogstraer. [The problem of provenance and tree breeding.] Tidsskr. Skogbruk. 58(9): 236-240. [In Norwegian.]

Concludes that although frost-resistant individuals of Sitka spruce may be found among material from the optimum zone of a southern provenance (State of Washington), these should not be used for tree breeding unless they are superior in vigor to plus trees of more northern provenance that are known to be frost resistant.

1341. _____
1960. Spontaneous and planted forest in west Norway. Vestlandet. Geogr. Stud., Skr. Norges Handelshoyskole, Geografiske Avhandl. 7, pp. 2, 18-34, illus.

Sitka spruce is the most important western North American tree species planted in west Norway. Experience with the species is discussed.

1342. _____
1962. Overvintringen av en-og to-ärig Sitkagran i planteskolene. [Overwintering of 1- and 2-year Sitka spruce in nurseries.] Arsskr. Norske Skogplantesk. 1961: 35-59 plus 1 table. [In Norwegian. English summary.]

1343. Robinson, Sir Roy L.
1931. Use of Sitka spruce in British afforestation. Forestry 5: 93-95.

Selection of Sitka spruce for afforestation operations in Britain has grown steadily for the 12 years prior to 1931. Sitka spruce is considered to be a maritime tree which finds maritime conditions in Britain.

1344. Rochester, G. H.
1933. The mechanical properties of Canadian woods, together with their related physical properties. Can. Dep. Int. Forest Serv. Bull. 82, 88 pp., illus.

1345. Roff, J. W., and Eades, H. W.
1959. Deterioration of logging residue on the British Columbia coast (western hemlock, amabilis fir, and Sitka spruce). Can. Forest. Prod. Lab. Tech. Note 11, 38 pp., illus.

During the first 3 years, decay losses amounted to over half the net volume: Sitka spruce was more, and amabilis fir less resistant than western hemlock. In western hemlock, decay was mainly of the brown cubical rot type, in Sitka spruce white rot was more prevalent, and in amabilis fir both types were about equal in importance. Deterioration of residue was affected by retention of bark and position of pieces relative to the ground, the occurrence of ambrosia-beetle infestations and of decays which originated in the standing tree and also by the length of material and the solar exposure. (From authors' summary.)

1346. Rogers, George W.
1960. Alaska in transition: the southeast region. 384 pp., illus. Baltimore: Johns Hopkins Press.

1347. Rogers, Ian Henry.
1967. Wood extractives: The structure and chemistry of some triterpenes isolated from the bark of Sitka spruce (*Picea sitchensis*). (Ph.D. thesis on file at Univ. Brit. Columbia.) Diss. Abstr.28: 3228B.

1348. Rohde, Th. von.
1936. Eine neue Krankheit der Sitkafichte in Deutschland. [A new disease of the Sitka spruce in Germany.] Z. Pflanzenkrankh. 46(6): 277-284, illus. [In German.]

1349. Ross, Charles R.
1966. Trees to know in Oregon. (Rev.) Oreg. State Coll. Ext. Serv. Bull. 697, 96 pp., illus.

1350. Ross, J. D.
1956. Chemical resistance of western woods. Forest Prod. J. 6: 34-37.

1351. Roth, Filibert.
1895. Timber: an elementary discussion of the characteristics and properties of wood. U.S. Dep. Agr. Bull. 10, 88 pp., illus.

1352. Rothamsted Experiment Station.
1960. Sitka seedling diseases. Rothamsted [England] Exp. Sta. Rep. 1959: 107-108.

The development of micro-organisms on roots of Sitka spruce seedlings taken from the nursery (started in 1925) at Kennington, near Oxford, was examined through the growing season. Three distinct diseases occurred: (1) there was preemergence and immediate postemergence damping-off; (2) at midsummer there was a sudden browning of the plants; (3) during early autumn the plants became stunted but with no discoloration. Seedling emergence on treated and untreated plots and probable pathogens are discussed.

1353. Rouse, G. D.
1948. Frost damage and recovery in Sitka spruce in the New Forest, Hampshire. Forestry 22(1): 62-63 plus 5 photos.

A plantation formed in 1921 was damaged by late spring frosts in 1927, 1928, and 1929. Investigations in 1947 showed that loss of leader did not necessarily result in a seriously deformed tree. Faster growing trees were quickest to recover.

1354. Roussel, L.
1965. Indications provisoires sur les exigences en lumiére de 12 essences forestieres resineuses. [Provisional indications of the light requirements of 12 coniferous forest species.] Soc. Forest. de Franche-Comte Bull. 33(5): 139-150, illus. [In French.]

Describes experiments designed to study light requirements of 12 conifer seedlings including Sitka spruce.

1355. Rowan, A. A.
1963. High pruning. Quart. J. Forest. 57(4): 320-327, illus.

Discusses the silvicultural implications of high pruning, particularly the need to thin so as to favor the pruned stems and achieve the maximum production of clean timber.

1356. _____
1967. Work study in the improvement of timber harvesting efficiency. Forest. Comm. Res. Develop. Pap. 59, 23 pp., illus.

Contains provisional standard time tables per pole for thinning, cross-cutting to Scottish pulpwood specifications, and hand-piling of Sitka spruce pulpwood.

1357. Rowe, J. S.
1959. Forest regions of Canada. Can. Dep. North. Aff. & Natur. Resources Forest. Br. Bull. 123, 71 pp., illus. (Rev. of Bull. 89, 1937.)

1358. Rudloff, E. von.
1964. Gas-liquid chromatography of terpenes. Part X. The volatile oils of the leaves of Sitka and Engelmann spruce. Can. J. Chem. 42: 1057-1062, illus.

1359. Rudnicki, J. M.
1951. Timber fasteners. *In* Canadian woods; their properties and uses. Ed. 2. Can. Forest. Br. Forest Prod. Lab. Div., pp. 305-320, illus.

1360. Rudolph, Emanuel D.
1966. Ecological succession: A summary. *In* Soil development and ecological succession in a deglaciated area of Muir Inlet, southeast Alaska. Inst. Polar Stud. Rep. 20, part 9, pp. 163-165 plus 2 tables.

Describes interrelationships that link soil development, plant succession and invasion, and population by various animals following recent deglaciation.

1361. Rühm, W.
1958. Zur mechanisch-chemischen und ökologischen Bekämpfung des Riesenbastkafers *Dendroctonus micans*. [Mechanical-chemical and ecological control of *D. micans*.] Z. Angew. Entomol. Rep. 43(3): 286-325. [In German. English summary.]

Discusses the reasons (drought, game damage, smoke injury, etc.) for the dangerous increase of this pest in Schleswig-Holstein, chiefly on Sitka spruce, and control measures successfully tried in two forests in Flensburg.

1362. _____
1959. Nematoden und Forstpflanzen. I. Mitteilung. Zur Bodenentseuchung in Forstbaumschulen und Forstkamps. [Nematodes and forest plants. I. Soil disinfestation in forest nurseries.] Merck-Blätter, Rep. Darmstadt 9(3): 1-16. [In German.]

Discusses the role of nematodes as a factor in "soil sickness" in nurseries, with special reference to conifers. A list of parasitic nematodes identified on conifers in Germany, the United States, and the Netherlands is given. In the conifer nurseries investigated, usually 20 percent of all nematode species present were parasitic, but the numerical density of parasitic species was often very great. *Rotylenchus robustus* was one of the most abundant. Sitka spruce appeared to be a highly susceptible species.

1363. Russell, Kenelm W.
1965. Conifer freeze damage 1964/65, Snohomish County, Washington. Wash. State Dep. Natur. Resources Res. Manage. Rep. 11, 8 pp.

1364. Ruth, Robert H.
1950. Cutting plans on logging costs in a 100-year-old stand of Sitka spruce and western hemlock. 118 pp. (M.F. thesis on file at Oreg. State Coll., Corvallis.)

1365. _____
1956. Plantation survival and growth in two brush-threat areas in coastal Oregon. USDA Forest Serv. Pacific Northwest Forest & Range Exp. Sta. Res. Pap. 17, 14 pp., illus.

In spring 1949, conifer plantations were established on a 44-acre site of Douglas-fir and an 81-acre site of Sitka spruce-western hemlock that had been clearcut 1 to 2 years earlier. Examinations over a 5-year period showed that competition with red alder, salmonberry (*Rubus spectabilis*), and associated shrubs was severe; only 37 percent of the planted Douglas-fir and about 25 percent of the planted spruce and hemlock survived. Recommendations are broadcast burning and early planting with large stock, plus chemical brush control as needed.

1366. _____
1957. Ten-year history of an Oregon coastal plantation. USDA Forest Serv. Pacific Northwest Forest & Range Exp. Sta. Res. Pap. 21, 15 pp., illus.

In a comparison of 10-year survival and growth, Douglas-fir survived better and grew faster than either Sitka spruce or Port-Orford-cedar. Effects of competing vegetation, animal damage, and aspect are reported and discussed.

1367. _____
1958. Silvical characteristics of Sitka spruce. USDA Forest Serv. Pacific Northwest Forest & Range Exp. Sta. Silvical Ser. 8, 19 pp., illus.

Summarizes information on the silvics of Sitka spruce including its relationship to climate, soils, topography, and associated species. Includes a description of its life history from seedling stage to maturity.

1368. _____
1965. Silviculture of the coastal Sitka spruce-western hemlock type. Soc. Amer. Forest. Proc. 1964: 32-36, illus.

Briefly describes the silvics of Sitka spruce and western hemlock, describes the coastal spruce-hemlock forest type, and summarizes current silvicultural practices.

1369. _____
1967. Silvicultural effects of skyline crane and high-lead yarding. J. Forest. 65: 251-255, illus.

Skyline crane yarding 77,000 board feet of logs per acre from steep slopes in the Sitka spruce-western hemlock type in coastal Oregon exposed 6.4 percent of the mineral soil, compared with 15.8 percent by conventional high-lead yarding. Differences were not statistically significant. Skidtrails tended to be across the slope, in contrast to high-lead skidtrails, which were mostly up and down slope. Damage to established tree seedlings and lesser vegetation was about the same for the two systems. The skyline crane system requires much less road construction than conventional systems, reducing construction costs as well as soil disturbance and land area taken out of production.

1370. _____ and Berntsen, Carl M.
1955. A 4-year record of Sitka spruce and western hemlock seedfall on the Cascade Head Experimental Forest. USDA Forest Serv. Pacific Northwest Forest & Range Exp. Sta. Res. Pap. 12, 13 pp., illus.

Six clearcut areas, ranging from 15 to 81 acres, received adequate seed from surrounding stands throughout their area. Seedfall started in the last 10 days of October and tapered off gradually until April and May. Western hemlock produced more seed than Sitka spruce. Seedfall under dense 100-year spruce-hemlock stands was 15 times that on clearcut areas. Viability of seed from the two species averaged 55 percent.

1371. _____ and Berntsen, Carl M.
1956. Chemical basal treatment to control red alder. USDA Forest Serv. Pacific Northwest Forest & Range Exp. Sta. Res. Note 128, 6 pp., illus.

Red alder often overtops conifer seedlings, including Sitka spruce, on certain sites in the Oregon Coast Ranges. Foliage spraying from the air is recommended for control on large areas, but on smaller areas basal treatment is best--especially for trees over 15 feet tall. Three solutions of 2,4-D or 2,4,5-T were used, and each proved successful. Results are tabulated. Chemical control cost about as much as hand girdling but had the advantage of preventing root sprouting.

1372. _____ and Silen, Roy R.
1950. Suggestions for getting more forestry in the logging plan. USDA Forest Serv. Pacific Northwest Forest & Range Exp. Sta. Res. Note 72, 15 pp.

Presents and discusses techniques and principles for preparation of intensive forestry-logging plans for the Sitka spruce-western hemlock and Douglas-fir forest types.

1373. _____ and Yoder, Ray A.
1953. Reducing wind damage in the forests of the Oregon Coast Range. USDA Forest Serv. Pacific Northwest Forest & Range Exp. Sta. Res. Pap. 7, 30 pp., illus.

Storm winds causing windthrow came from the S.S.W. On the borders of clearcut areas, 93 percent of the wind damage occurred along the north and east boundaries, especially when these boundaries were on the leeward side of a ridge. No correlation was found between wind damage and size of cutting, but areas less than 2 acres sustained considerable loss. In stands

from which 16 to 24 percent of the volume had been removed in thinnings, losses from windthrow averaged 80 board feet per acre per year, while losses were heavy in other areas from which most of the dominant and codominant trees had been removed. Douglas-fir and Sitka spruce were more windfirm than western hemlock, and trees infected with root rot were particularly liable to windthrow. Windthrow is more severe on areas with a high watertable or very shallow soil. In virgin stands heaviest damage occurred on the lee side of ridges, beginning near the crest of the ridge and extending for some distance down the lee slope, and also on small ridges and level areas in the lee of higher ridges. Recommendations are made on cutting practices to reduce windthrow.

1374. Ruth, Robert Harvey.
1967. Differential effect of solar radiation on seedling establishment under a forest stand. 176 pp., illus. (Ph.D. thesis on file at Oreg. State Univ., Corvallis.)

Sitka spruce, western hemlock, and Douglas-fir seedlings all became established more readily on mineral soil under a forest canopy than did red alder. The ratio of viable seed sown in the spring to establish seedlings in the fall was 5.8 for the conifers compared with 46.7 for alder. Radiation had surprisingly little effect on seedling establishment but played an important role in first season growth. Spruce and hemlock growth increased with radiation up to an average daily radiation of about 150 Langleys, then decreased at higher radiation levels. The decrease was attributed to high soil moisture tension.

1375. Rutter, A. J.
1955. The relation between dry weight increases and linear measures of growth in young conifers. Forestry 28(2): 125-135, illus.

Briefly examines a number of measurements of growth and dry weight of young crops of *Pinus sylvestris* and *Picea sitchensis* and concludes that, at any time before the canopy is closed, dry weight is more closely related to basal diameter than to height.

1376. Sabroe, A. S.
1947. Forestry in Denmark: A guide to our guests. Ed. 2, Danish Forest Soc., 114 pp., illus.

Includes a bibliography and who's who in forestry. Entirely in English. Sitka spruce was introduced in Denmark about 1875 and has been planted extensively of late bacause of its vigorous growth and frugality. *Fomes annosus*, however, does more harm to this species than to Norway spruce.

1377. Salt, G. A.
1963. Disease of Sitka spruce seedlings. Rothamsted [England] Exp. Sta. Rep. 1962: 122-123.

The number of seedlings obtained from 1,800 viable seeds per square yard differed greatly between nurseries, when all were sown under ideal conditions in March. Seed treatment with methoxyethyl mercury chloride reduced preemergence loss and increased numbers but had no effect on postemergence dampingoff, or on seedling height. Partial soil sterilization with formalin and chloropicrin controlled damping-off and substantially increased heights. Soil and seed treatments together produced the best results.

1378. _____
1964. Diseases of Sitka spruce seedlings in forest nurseries. Rothamsted [England] Exp. Sta. Rep. 1963: 114-116.

Dazomet (Mylone) proved as effective as formalin as a soil sterilant and has the practical advantage of being applied as a dry powder. Of fungi on root debris remaining in seedbeds from one year to the next, *Cylindrocarpon* sp. was most often isolated. Others were *Fusarium* sp. and *Pythium* sp. Although partial sterilants almost eliminated these three genera from debris, the material was colonized by other fungi rare or absent in isolations from untreated material. In tests of pathogenicity of pure cultures, all species of *Pythium* killed most seedlings before emergence. *Cylindrocarpon* and several species of *Fusarium*, *Phoma*, and *Botrytis* behaved as weak pathogens by decreasing emergence and causing some postemergence deaths.

1379. _____
1964. Pathology experiments on Sitka spruce seedlings. *In* Report on forest research for the year ended March 1963. Great Brit. Forest. Comm., pp. 83-87. London: H. M. Stationery Office.

1380. _____
1965. Pathology experiments on Sitka spruce seedlings. *In* Report on forest research for the year ended March 1964. Great Brit. Forest. Comm., pp. 89-95. London: H. M. Stationery Office.

Describes continuing study of causes of stunting and the nature of growth responses to partial sterilization of soil in old forest nurseries.

1381. _____
1966. Pathology experiments on Sitka spruce seedlings. *In* Report on forest research for the year ended March 1965. Great Brit. Forest. Comm., pp. 97-102. London: H. M. Stationery Office.

1382. _____
1966. Diseases of Sitka spruce seedlings in forest nurseries. Rothamsted [England] Exp. Sta. Rep. 1965: 133-134.

1383. _____
1967. Pathology experiments on Sitka spruce seedlings. *In* Report on forest research for the year ended March 1966. Great Brit. Forest. Comm., pp. 104-108. London: H. M. Stationery Office.

The following fungi isolated from Sitka spruce seed were associated with germination failure and were reisolated consistently from dead seeds or seedlings: *Phizoctonia solani*, *Cylindrocarpon*, *Gliocladium roseum*, and unidentified psychrophilic fungus. Losses were greater when seed was incubated at 10° than at 20° or 5° C. and were decreased by treating seed with thiram dust. (From author's summary.)

1384. _____
1967. Pathology experiments on Sitka spruce seedlings. *In* Report on forest research for the year ended March 1967. Great Brit. Forest. Comm., pp. 141-146. London: H. M. Stationery Office.

An endophytic fungus in Sitka spruce seed greatly decreased the viability of dormant seed incubated for 4 weeks at 10° C. in sterilized quartz grit or in unsterilized nursery soil. Seed incubated at 15° C. and 20° C. germinated and escaped serious damage. Infection was prevented and viability maintained at 10° C. by treating seed with a 50-percent thiram dust. Seed from the same bulk as used in the laboratory, when sown in nursery seed beds in 1965 and 1966, mostly survived and germinated, but many seedlings became infected by species of *Pythium*, *Fusarium*, and *Cylindrocarpon* and died soon after they emerged. (Author's summary.)

1385. Sanzen-Baker, R. G., and Nimmo, M.
1941. Glazed frost 1940--damage to forest trees in England and Wales. Forestry 15: 37-54.

Damage to Sitka spruce was often severe but less than damage to larch or Douglas-fir. In both young and middle-aged plantations, dominant trees with large crowns overtopping their neighbors received worst damage, particularly in young stands of Sitka spruce and Douglas-fir.

1386. Sargent, C. S.
1885. The woods of the United States. With an account of their structure, qualities, and uses. With geographical and other notes on the trees which produce them. 203 pp., illus. New York: D. Appleton & Co.

1387. _____
1897. The forests of Alaska. Gard. & Forest 10(501): 379-380.

1388. Sargent, Charles S.
1884. Report on the forest of North America (exclusive of Mexico). U.S. Dep. Int. Census Office. 612 pp., illus.

Briefly describes Sitka spruce and its occurrence in the United States, with information on wood properties.

1389. Sargent, Charles Sprague.
1898. The silva of North America. A description of the trees which grow naturally in North America exclusive of Mexico. Vol. 12 (Coniferae), 144 pp., illus. Boston and New York: Houghton, Mifflin & Co.

Includes a description of the silvical characteristics of Sitka spruce and a line drawing showing foliage, cones, and cone parts.

1390. _____
1933. Manual of the trees of North America (exclusive of Mexico). Ed. 2, 910 pp., illus. Boston and New York: Houghton, Mifflin & Co.

1391. _____
1961. Manual of the trees of North America (exclusive of Mexico). 2d corrected ed., vols. 1 & 2, 910 pp., illus. New York: Dover Publications.

1392. Savile, D. B. O.
1955. Chrysomyxa in North America--additions and corrections. Can. J. Bot. 33: 487-496.

1393. Savory, J. G., and Packman, D. F.
1954. Prevention of decay of wood in boats. With a contribution on electrochemical attack. Great Brit. Dep. Sci. Ind. Res. Forest Prod. Res. Bull. 31, 17 pp. plus 8 plates.

Describes decay of wood in boats and methods of prevention. Sitka spruce is listed as a "nondurable" wood, this grade being given quantitative meaning in that the life of a 2- by 2-inch specimen in the ground is between 5 and 10 years old.

1394. Schaefer, R. J.
1967. Three cheers for the "America." Amer. Forests 73(9): 4-7, 42, illus.

Briefly describes America's cup winner, "America." Sitka spruce was used for deck beams.

1395. Schefer-Immel, Verena.
1958. Einige Bemerkungen zur Biologie und zum Einfluss von Temperatur und rel. Luftfeuchtigkeit auf die Entwicklung von Ei, Raupe und Puppe von *Boarmia bistortata* Goeze (Lepidoptera, Geometridae). [Notes on the biology of *B. bistortata* and the effect of temperature and relative humidity on egg, larva, and pupa.] Z. Angew. Entomol. 42(3): 307-315, illus. [In German. English summary.]

In laboratory experiments the looper moth larvae ate foliage of larch, Sitka spruce, poplars, and lettuce but preferred larch.

1396. Scheffer, T. C., and Browne, F. L.
1954. Tests of some superficial treatments of exposed wood surfaces for their protection against fungus attack. J. Forest Prod. Res. Soc. 4(3): 131-132.

1397. Scheffer, Theodore C., Wilson, T. R. C., Luxford, R. F., and Hartley, Carl.
1941. The effect of certain heart rot fungi on the specific gravity and strength of Sitka spruce and Douglas-fir. U.S. Dep. Agr. Tech. Bull. 779, 24 pp., illus.

The appearance of Sitka spruce wood attacked by *Polyporus schweinitzii* was not a good indication of the degree of decay up to the point where wood broke up into cubical masses. The white pockets that characterize the decay of *Fomes pini* provided a good progress indicator. A 20-percent loss in shock resistance of Sitka spruce when infected with *P. schweinitzii* was found, even when infection could only be detected by microscope or culture.

1398. Scheller, H. D. Von.
1958. Massenvermehrung der Sitkafichtenlaus, *Elatobium* (=*Liosomaphis*) *abietina* WALK in Nordwestdeutschland. [Outbreak of *E. abietina* in northwest Germany.] Anz. Schadlingsk 31(6): 85-88, illus. [In German.]

E. abietina has existed for years in small numbers in Schleswig-Holstein. In 1957, however, favored by weather, a definite outbreak occurred on Sitka spruce. Notes are given on hosts (a number of *Picea* spp.), damage inflicted, and natural enemies. Control measures had undesirable side effects, especially on natural enemies. The best time for dusting is early spring. The pest prefers shade and is found in greatest numbers in dense, poorly thinned stands.

1399. _____
1962-63. Zur Biologie und Schadwirkung der Nadelholzspinnmilbe *Oligonychus ununguis* Jacobi (Acar. Tetr.) und der Fichtenrohrenlaus *Liosomaphis abietina* Walker (Hom. Aphid.). [Biology and injurious effects of *O. ununguis* Jacobi (Acar. Tetr.) and *L. abietina* Walker (Hom. Aphid.).] Z. Angew. Entomol. 51(1): 69-85, illus.; 51(3): 258-284, illus. [In German.]

1400. Schenck, C. A.
1912. The art of the second growth or, American sylviculture. Ed. 3, 206 pp. Albany, New York: The Brandow Printing Co.

1401. Schimitschek, Von Erwin, and Wienke, Elisabeth.
1963. Untersuchungen uber die Befallsbereitschaft von Baumarten fur Sekundarschadlinge. I. [Research studies of susceptibility of conifers to secondary parasites.] Z. Angew. Entomol. 51(3): 219-257. [In German.]

Describes an investigation of the physiological basis for attack of Sitka spruce by *Dendroctonus micans*. Bark anatomy, sap-stream velocity, transpiration, osmotic pressure, and electrical resistance in bark are considered.

1402. Schmidt, R. L.
1957. The silvics and plant geography of the genus *Abies*. Dep. Lands & Forests, Brit. Columbia Tech. Pub. T-46, 31 pp., illus.

Sitka spruce occurs in mixture with *Abies lasiocarpa* at Meziadin Lake, B.C. (latitude 56°).

1403. Schmiege, D. C.
1966. Mortality of overwintering eggs of the black-headed budworm and hemlock sawfly in southeast Alaska. Northern Forest Exp. Sta. USDA Forest Serv. Res. Note NOR-15, 4 pp., illus.

1404. _____ and Hard, J. S.
1966. Oviposition preference of the black-headed budworm and host phenology. Northern Forest Exp. Sta. USDA Forest Serv. Res. Note NOR-16, 5 pp., illus.

Phenology of western hemlock and Sitka spruce shoot growth in relation to budworm hatch and development was studied on two aspects. Shoot growth of both tree species was greater and started earlier on south rather than north aspects. Budworm development followed the same pattern. Peak hatch occurred when hemlock buds began expansion and when spruce shoots had completed about 50 percent of their growth. In preference tests, budworms preferred hemlock for egg laying regardless of species on which they were

reared. Budworms may lay eggs on spruce during prolonged outbreaks when hemlock is severely defoliated, but it is likely that fewer of the larvae survive because the rapidly expanding spruce shoots provide less shelter.

1405. Schmiege, Donald C.
1965. The fecundity of the black-headed budworm *Acleris variana* (Fern.) (Lepidoptera: Tortricidae) in coastal Alaska. Can. Entomol. 97: 1226-1230.

The oviposition and fecundity of field- and lab-reared specimens of the black-headed budworm, *Acleris variana* (Fern.), are reported.

1406. Schneider, Von I.
1961. Ein schädliches Auftreten des Fichtenblasenfusses, *Taeniothrips pini* Uz., an Maitrieben der Sitkafichte (*Picea sitchensis* Traut. und Mey.). [An outbreak of *T. pini* on spring shoots of Sitka spruce.] Anz. Schadlingsk 34(9): 135-137, illus. [In German.]

T. pini was found in 1958 in the forest district of Trittau near Hamburg in a 17-year stand of Norway and Sitka spruce. A survey was made in subsequent years of the distribution of the insect near Hamburg and in Schleswig-Holstein, and information is presented on its biology and life history. Damage was negligible except where ornamental branches of Sitka spruce were spoiled.

1407. Schneider, Isolde.
1962. Die Nadelholzspinnmilbe, *Paratetranychus ununguis* Jac. (Acari, Trombidiformes), auf den Aufforstungsflachen Schleswig-Holsteins. [*P. ununguis* Jac. of afforestation areas in Schlesvig-Holstein.] Allg. Forst- und Jagdzeit. 133(6): 144-148, illus. [In German. English summary.]

1408. _____
1966. Aussetzung von *Aphidecta obliterata* L. (*Coccinellidae*) auf der Nordseeinsel Amrum zur biologischen kontrolle der Sitkalaus (*Liosomaphis abietina* Walk. *Aphididae*). [Introduction of *A. obliterata* into the North Sea Island of Amrum for the biological control of *L. abietina*.] Anz. Schadlingsk 39(2): 26. [In German.]

1409. Schneider, Roswitha, and Paetzholdt, Marcus.
1964. *Ascochyta piniperda* als Erreger eines Triebsterbens an Blaufichten in Baumschulen. [*A. piniperda* as the cause of shoot blight of *Picea pungens* in nurseries.] Nachrichtenbl. Deut. Braunschweig. 16(5): 73-75, illus. [In German.]

1410. Schober, H.
1956. Ergebnisse von Anbauversuchen mit ausländischen Holzarten. [Results of trials of exotics.] Ned. Boschbouw-Tydsehr 28(8): 187-202, illus. [In German.]

Describes briefly the results of trials in Germany since about 1880 of a number of tree species, the most important being Douglas-fir, Sitka spruce, Japanese larch, and *Quercus borealis*.

1411. Schober, Reinhard.
1962. Die Sitka-Fichte. Eine biologisch-ertragskundliche Untersuchung. [*Picea sitchensis*. A study of its biology and yield.] Schr. Reihe Forstl. Fak. Univ. Gottingen 24/25, 230 pp., illus. [In German. English summary.]

A monograph, based chiefly on a study of 111 temporary and 58 permanent sample plots (45 German, 9 Danish, 3 British, and 1 Swedish), discussing climatic and soil requirements; injuries by fungi (particularly *Fomes annosus*), insects (particularly *Dendroctonus micans*), deer, drought, frost, wind, etc.; silviculture; suitable provenances; behavior in mixtures; growth of individual trees, yield and wood properties (the latter in a chapter by W. Knigge). Taper and volume tables are presented on the basis of an analysis of 1,234 stems, also tables of stem distributions, volume distribution over diameter classes, height-curve tables, and assortment tables for individual trees and stands. Yield tables for Germany, Denmark, Great Britain, and Sweden are compared. Rotations of 70 to 80 years or more are considered profitable. (From author's summary.)

1412. Schoonover, Shelley E.
1951. American woods. 250 pp., illus. Santa Monica, Calif.: Watling & Co.

1413. Schrader, O. Harry.
1943. The effect of grouped scarf joints in clear, laminated, glued beams of Douglas-fir and Sitka spruce. Timberman 44(9): 49-50, 52, 54, 57, illus.

1414. Schreiner, Ernst J.
1937. Improvement of forest trees. U.S. Dep. Agr. Yearbook 1937: 1242-1279, illus.

Lists among natural hybrids of forest trees *Picea sitchensis* X *P. canadensis*.

1415. Schubert, G. H.
1952. Germination of various coniferous seeds after cold storage. Calif. Forest & Range Exp. Sta. Res. Note 83, 7 pp.

Germination of Sitka spruce seed stored at 41° F. in airtight containers for 6 to 10 years was 68 percent. Seed stored 11 to 20 years germinated only 2 to 6 percent.

1416. Schwenke, H. J.
1960. Koniferenanzucht in einen neuartigen Saatbeet. [Raising conifers in a new type of seedbed.] Forst- und Holzwirt 15(10): 193-195, illus. [In German.]

The bed, 1 to 1.2 meters wide and about 20 centimeters deep, is dug out and filled in winter with 18 centimeters of compost (larch litter, larch raw humus, and slightly loamy humus sand plus grass and some fertilizers). This is topped with a 5-centimeter layer of a mixture of washed quartz sand (50 percent by volume), rubbed peat (25 percent), and chopped sphagnum moss (25 percent) to form the actual seedbed. The management and advantages of such beds are discussed and details are given on the growth of

1- and 2-year-old seedlings of nine coniferous species in the beds. The beds have proved good even with species usually difficult to raise, such as Sitka spruce.

1417. Scott, C. W.
1952. The properties and uses of conifer thinnings in Great Britain. Forestry 25(1): 1-9.

1418. _____ and MacGregor, W. D.
1953. Fast-grown wood, its features and value, with special reference to conifer planting in the United Kingdom since 1919. Forestry 26(2): 123-140.

1419. Scott, David R. M.
1962. Plant associations of western Washington. Univ. Wash. Arboretum Bull. 25(1): 11-14, 26.

1420. _____
1962. The Pacific Northwest region, pp. 503-570, illus. *In* Regional silviculture of the United States, John W. Barrett [ed.]. New York: The Ronald Press Co.

1421. _____
1962. The Alaska region, pp. 571-591, illus. *In* Regional silviculture of the United States, John W. Barrett [ed.]. New York: The Ronald Press Co.

1422. Seal, D.
1957. The supply of "home-collected" conifer seeds in Scotland. Arbor (Aberdeen) 3(1): 13-16.

1423. Seal, D. T., Matthews, J. D., and Wheeler, R. T.
1965. Collection of cones from standing trees. Great Brit. Forest. Comm. Forest Rec. 39, 48 pp., illus.

One bushel of Sitka spruce cones contains 1,300 cones and will yield an average of 11 ounces of cleaned seed. Approximately 29,000 seedlings may be produced from this seed, from which 10,000 transplants may be obtained. Seedling yields are extremely variable. Information is presented in tabular form for 15 conifer species including Sitka spruce.

1424. Selbo, M. L.
1963. Effect of joint geometry on tensile strength of finger joints. Forest Prod. J. 13: 390-400, illus.

Describes methods of marking and testing finger joints. Sitka spruce, Douglas-fir, and white oak were tested. Data on strength in relation to geometry of the joints are given, with guides for jointing.

1425. Serenius, R. S.
1956. Sulphite pulping of western hemlock, balsam, and spruce. Pulp & Pap. Mag. Can. 57(9): 133-137, illus.

Gives tables and graphs to show the yields and strengths of the pulps of the three species at constant permanganate number, cooking schedules,

and screenings content. Also illustrates how the data from an experimental digester can be applied on a mill scale for various combination ratios of the raw materials.

1426. Shacklette, Hansford T.
1962. Biotic implications of Alaskan biogeochemical distribution patterns. Ecology 43(1): 138-139.

Young stems and leaves of 34 species of trees and shrubs, including Sitka spruce, growing in four regions of Alaska were analyzed chemically for copper, lead, zinc, and nickel content.

1427. Shanklin, John F.
1954. Natural areas. J. Forest. 52: 375-383.

1428. _____
1960. Society of American Foresters natural areas. J. Forest. 58: 905-917.

Lists natural areas recognized by the Society of American Foresters; includes those containing stands of Sitka spruce.

1429. Shantz, H. L., and Zon, R.
1924. Natural vegetation. *In* Atlas of American agriculture, part 1, sect. E., pp. 1-29, illus. U.S. Dep. Agr.

1430. Sharpe, Grant William.
1956. A taxonomical-ecological study of the vegetation by habitats in eight forest types of the Olympic rain forest, Olympic National Park, Washington. Diss. Abstr. 16(5): 1043. (Ph.D. thesis on file at Univ. Wash., 335 pp.)

1431. Shaw, C. G., and Harris, M. R.
1960. Important diseases and decays of trees native to Washington. Wash. State Univ. Agr. Ext. Serv. Bull. 540, 35 pp.

1432. Shaw, Charles Gardner.
1958. Host fungus index for the Pacific Northwest. I. Hosts. Wash. Agr. Exp. Sta. Cir. 335, 127 pp.

Thirty-seven fungi are listed as attacking Sitka spruce.

1433. Shaw, Elmer W.
1953. Direct seeding experiments on the 1951 Forks Burn. USDA Forest Serv. Pacific Northwest Forest & Range Exp. Sta. Res. Pap. 9, 19 pp., illus.

A 40-acre burned-over study area in the Olympic National Forest was seeded by helicopter with a mixture of *Picea sitchensis*, *Pseudotsuga taxifolia*, *Tsuga heterophylla*, and *Chamaecyparis lawsoniana*. One year after sowing, 45 percent of the milacre plots were stocked with one or more live seedlings. Seedling survival by species during the first year was *P. taxifolia*, 45 percent; *T. heterophylla*, 32 percent; *P. sitchensis*, 18 percent; and *C. lawsoniana*, 16 percent. Some suggestions for improving methods of studying the effectiveness of direct seeding are made.

1434. Shaw-Stewart, Hugh.
1929. Report on various aspects of Sitka spruce on Ardgowah Estate, and various deductions arrived at. Scot. Forest. J. 43: 1-4.

1435. Shea, Keith R.
1960. Decay in logging scars in western hemlock and Sitka spruce. Weyerhaeuser Co. Forest. Res. Note 25, 7 pp. plus 6 tables.

Examination of 151 stems in a 90-year stand in Washington showed 187 scars dating from partial cutting 17 years before. Scars were most frequent on the stump and buttress roots, indicating that skidding was an important source of injury. Evidence of decay was found in 91 percent of scars on western hemlock and 88 percent of scars on Sitka spruce; losses due to decay averaged 0.9 percent of total merchantable volume. The decay-causing organisms are discussed.

1436. _____
1960. Deterioration--a pathological aspect of second-growth management in the Pacific Northwest. Weyerhaeuser Co. Forest. Res. Note 28, 16 pp., illus.

Discusses decay and deterioration associated with various forms of damage and causes of death. Tables and graphs are given for estimating probable volume of decay associated with scars of different size and age.

1437. _____
1960. Fungus succession and the significance of environment in the deterioration of logs. Weyerhaeuser Co. Forest. Res. Note 30, 7 pp.

Reviews some of the requirements for growth of wood-inhabiting fungi and cites some examples of fungus succession and significance of environment. Sitka spruce is included.

1438. _____
1964. *Rosellinia herpotrichioides* on Sitka spruce seedlings in Washington. Plant Dis. Rep. 48(6): 512-513, illus.

The fungus has caused mortality on 2-0 Sitka spruce seedlings in nursery beds. The disease was at its worst toward the center of overstocked beds, suggesting that high humidity and poor aeration favor the fungus. Reduced stocking to improve aeration is recommended. The disease is described. This is the first report of the disease in Washington on Sitka spruce and Douglas-fir seedlings.

1439. Sheldon, E. P.
1904. The forest wealth of Oregon. Lewis & Clark Exposition Comm., Portland, 32 pp., illus.

1440. Shelford, Victor E.
1963. The ecology of North America. 610 pp., illus. Urbana: Univ. Illinois Press.

Includes descriptions of Sitka spruce forest communities with particular emphasis on animal life in the forest.

1441. Sigafoos, Robert S.
1958. Vegetation of northwestern North America, as an aid in interpretation of geologic data. U.S. Geol. Surv. Bull. 1061-E: 165-185, illus., plus map.

1442. Siggins, Howard W.
1933. Distribution and rate of fall of conifer seeds. J. Agr. Res. 47(2): 119-128, illus.

Describes tests to determine the rate of seedfall of several conifer species in still air. Seed size in relation to fall rate is considered. Sitka spruce seed from California on the average weighed 0.0034 grams and fell at the rate of 3.1 feet per second.

1443. Silen, Roy R., and Woike, Leonard R.
1959. The Wind River Arboretum from 1912 to 1956. USDA Forest Serv. Pacific Northwest Forest & Range Exp. Sta. Res. Pap. 33, 50 pp., illus.

Of the 20 species of spruce tried in the arboretum, 16 are doing fairly well but only *Picea abies* has done well enough to warrant further forest planting trials. Sitka spruce was attacked by *Chermes cooleyi* and also damaged by sapsuckers.

1444. Silver, G. T.
1962. The Sitka spruce weevil. Can. Forest Entomol. Pathol. Br. Annu. Rep. year ended March 31, 1962, p. 128.

1445. _____
1964. The Sitka spruce weevil. Can. Forest Entomol. Pathol Br. Annu. Rep. year ended March 31, 1963, p. 131.

Studies on the Sitka spruce weevil, *Pissodes sitchensis* Hopk. were continued with emphasis on completing the life history portion of the project. Weevils overwinter in the duff, start emerging in late April, and are present in the field until mid-July. Individual adults have lived up to 6 weeks in cages. Larvae are present from mid-May until December. New adults start emerging in late August and feed before hibernation.

1446. Simonson, Roy W., and Rieger, Samuel.
1967. Soils of the Andept suborder in Alaska. Soil Sci. Proc. 31(5): 692-699, illus.

Describes the major well-drained soils of nonmountainous areas of Kodiak Island, the Aleutian Islands, the Alaska peninsula, and the southwestern Kenai Peninsula. The soils were formerly classified in the Ando group on the basis of similarities to that group as originally proposed in Japan. Field relationships and the shared characteristics of B horizons suggest that Andepts are readily converted to Orthods (Podzols) following occupation by Sitka spruce forest.

1447. Sinden, John A.
1964. An economic analysis to aid the marginal decision on rotation length. I. Presentation of the principle. Forestry 37(2): 161-178.

Discusses general principles, using a specific Sitka spruce stand type as an example.

1448. Skinner, Edgel C.
1959. Cubic volume tables for red alder and Sitka spruce. USDA Forest Serv. Pacific Northwest Forest & Range Exp. Sta. Res. Note 170, 4 pp.

Presents three tables supplementing or amending those previously published by the Station: Volume tables for permanent sample plots as recommended by the Puget Sound Research Center advisory committee for use in western Washington (28 tables (processed), 1953).

1449. Slade, Walter B.
1930. Drying Sitka spruce for airplane use. West Coast Lumberman 57(1): 18, 23.

1450. Sloan, G. M.
1957. Public Inquiries Act (British Columbia): Report of the Commissioner...relating to the forest resources of British Columbia, 1956. 2 vol., 888 pp. plus map. Victoria, Brit. Columbia: Queen's Printer.

1451. Smith, Clinton G.
1921. Regional development of pulpwood resources of the Tongass National Forest, Alaska. U.S. Dep. Agr. Bull. 950, 40 pp., illus.

1452. Smith, D. N.
1959. The natural durability of timber. Great Brit. Dep. Sci. Ind. Forest Prod. Res. Rec. 30 (Wood Preserv. Ser. 4), ed. 2, 26 pp., illus.

1453. _____ and Cockcroft, R.
1961. The preservative treatment of home-grown timbers by diffusion. Wood 26(12): 490-492, illus.

Exploratory experiments using a boron preservative have shown that fresh-sawn Sitka spruce can be penetrated through to the center by diffusion and have indicated the kind of preservative distribution obtained. The time required for diffusion was 3 weeks for material 1 inch thick, and 3 to 4 months for material 3 inches thick.

1454. Smith, DeWilton C.
1965. Planning a timber harvest in Alaska. J. Forest. 63: 341-343, illus.

1455. Smith, J. H. G., and Ker, J. W.
1957. Timber volume depends on D^2H. B.C. Lumberman 41(9): 28, 30.

Constants a and b for 24 tree species are given for the combined variable formula in which tree volume is estimated in terms of d.b.h. squared (D^2) and total height (H).

$$V = a + b \frac{D^2H}{100}$$

where V is volume. Constants for Sitka spruce are given for immature trees (all diameters) and for mature trees in three diameter classes. Standard errors are tabulated for very short and very tall trees.

1456. Smith, J. Harry G.
1964. Root spread can be estimated from crown width of Douglas-fir, lodgepole pine, and other British Columbia tree species. Forest. Chron. 40: 456-473, illus.

1457. _____ and Breadon, Robert E.
1964. Combined variable equations and volume-basal area ratios for total cubic-foot volumes of the commercial trees of B.C. Forest. Chron. 40: 258-261.

1458. Smitt, Anton.
1950. Fremmede treslag i vest-Norge. [Exotic species in western Norway.] Tidsskr. Skogbruk 58(6): 115-122, illus. [In Norwegian.]

Gives tabulated data on the quantities of seeds and plants of some exotic species used between 1928 and 1949 and of volume and increment from stands of Sitka spruce and other conifers.

1459. Smythe, D. M.
1921. *Abies menziesii* at Keilour, Perthshire. Roy. Scot. Arboretum Soc. Trans. 35: 82.

One of the first Sitka spruce planted in United Kingdom is said to have been planted in Scotland in 1834. When blown down in 1920 it was 103 feet tall.

1460. Society of American Foresters.
1964. Forest cover types of North America (exclusive of Mexico). 67 pp. Washington, D.C.

Presents a grouping of stands of similar composition and development into forest cover types. Sitka spruce type 223 consists of 80 percent or more Sitka spruce in the dominant crown canopy. Sitka spruce-western hemlock type 225 contains both species but neither in sufficient amount to constitute a pure type (80 percent). Nature and occurrence and transition forms and variants are described.

1461. Sødergaard, Poul.
1965. Kimplanternes morfologi og udvikling hos de I skovbruget almindeligt anvendte naletraeer. [Identification of one- and two-year seedlings of 25 conifers.] Dansk Dendrol. Arsskr. 2(11): 185-247, illus. [In Danish.]

1462. Somerville, H. C., and Stewart, G. G.
1957. A note on a high elevation wood in Midlothian. Scot. Forest 11(1): 23-25.

Describes a plantation made about 1870 at 1,600- to 1,675-foot elevation with a mixture of Norway, white, and Sitka spruce. The Sitka spruce performed better than either of the other two spruces.

1463. Sorenson, I. C.
1913. Akklimatiseret Sitkagran. [Acclimation of Sitka spruce.] Hedeselskabets Tidsskr. 1913: 267. [In Danish.]

1464. Sowder, A. M.
1961. 1960 Christmas tree data. J. Forest. 59: 829-830.

The 1960 total production of Christmas trees in the United States was 31,361,512 trees, of which 5,040 were Sitka spruce.

1465. Spada, Benjamin.
1962. Forest statistics for ısland and Kitsap Counties, Washington, 1959; San Juan County, Washington, 1960. USDA Forest Serv. Pacific Northwest Forest & Range Exp. Sta. Forest Surv. Rep. 142, 27 pp.

1466. _____
1962. Forest statistics for King County, Washington. USDA Forest Serv. Pacific Northwest Forest & Range Exp. Sta. Forest Surv. Rep. 143, 27 pp., illus.

1467. _____
1962. Forest statistics for Jefferson County, Washington. USDA Forest Serv. Pacific Northwest Forest & Range Exp. Sta. Forest Surv. Rep. 144, 26 pp.

1468. _____
1962. Forest statistics for Clallam County, Washington. USDA Forest Serv. Pacific Northwest Forest & Range Exp. Sta. Forest Surv. Rep. 145, 26 pp.

1469. Sparhawk, W. N.
1919. Supplies and production of aircraft woods. U.S. Nat. Adv. Comm., Aeron. Rep. 67, 62 pp.

1470. Spaulding, Perley.
1956. Diseases of North American forest trees planted abroad. An annotated list. U.S. Dep. Agr. Handbook 100, 144 pp.

Lists 17 pathogens of Sitka spruce and locations in 19 countries where Sitka spruce has been planted.

1471. _____
1961. Foreign diseases of forest trees of the world. An annotated list. U.S. Dep. Agr. Handbook 197, 361 pp.

Lists *Ascochyta piniperda*, *Chrysomyxa ledi* var. *rhododendri*, *Pezicula livida*, and *Sparassis ramosa* as attacking Sitka spruce.

1472. Spencer, Alice.
1918. The spiral spruce. Amer. Forest. 24: 342, illus.

Describes a specimen of Sitka spruce from Alaska with concentric rings of dense wood in cross section, giving a "bull's eye" appearance.

1473. Spencer, D. A., and Kverno, N. B.
1953. Research in rodent control to promote reforestation by direct seeding. U.S. Fish & Wildlife Serv. Progr. Rep. 3, 56 pp. plus 29 tables, 14 diagrams, and 17 graphs.

1474. Sprague, Roderick, and Lawrence, Donald B
1959. The fungi on deglaciated Alaskan terrain of known age. I. Mendenhall Glacier Area. Wash. State Univ. Res. Stud. 27(3): 110-128, illus.

Reports on a study of development of vegetation and soil in southeastern Alaska, with emphasis on the fungi and their effect on decay of organic matter. Sitka spruce is an important member of the plant associations studied. Parts II and III are listed below.

1475. _____ and Lawrence, Donald B.
1959. The fungi on deglaciated Alaskan terrain of known age. II. Herbert Glacier Area. Wash. State Univ. Res. Stud. 27(4): 214-229, illus.

1476. _____ and Lawrence, Donald B.
1960. The fungi on deglaciated Alaskan terrain of known age. III. Glacier Bay Area. Wash. State Univ. Res. Stud. 28(1): 1-20, illus.

1477. Spurr, Stephen H.
1953. Post-war forestry in western Europe. Part 1.--England and Scotland. J. Forest. 51: 195-199.

1478. Spurway, C. H.
1941. Soil reaction (pH) preferences of plants. Mich. State Coll. Agr. Exp. Sta. Spec. Bull. 306, 36 pp.

Optimum soil pH range for Sitka spruce is 5.0 to 6.0. Maximum pH limit, beyond which damage may occur, is 7.0.

1479. Srivastava, T. N.
1951. The application of selective herbicides to forestry practice. Indian Forest. 77(3): 176-191 plus 4 plates.

1480. Stackelberg, S. Freiherr Von.
1963. Zeitbedarf und Energieverbrauch bei der winkelpflanzung. [Time and energy consumption in planting.] Allg. Forst- und Jagdzeit. 134(9): 244-254. [In German. English summary.]

A time and motion study of planting Sitka and Norway spruce.

1481. Stamm, A. J.
1929. The capillary structure of softwoods. J. Agr. Res. 38(1): 23-67.

Examines in detail, by dynamic physical methods, the capillary structure of six western conifers including Sitka spruce.

1482. _____
1959. Effect of polyethylene glycol on the dimensional stability of wood. Forest Prod. J. 9: 375-381, illus.

Polyethylene glycol-1000 stabilizes wood by bulking the fibers. It also serves as a chemical seasoning agent, suppressing decay in high concentrations, and has slight effect on physical properties, gluing, or finishing.

1483. _____ and Baechler, R. H.
1960. Decay resistance and dimensional stability of five modified woods. Forest Prod. J. 10: 22-26, illus.

1484. Stamm, Alfred J.
1946. Passage of liquids, vapors and dissolved materials through softwoods. U.S. Dep. Agr. Tech. Bull. 929, 80 pp., illus.

1485. _____
1953. Diffusion and penetration mechanism of liquids into wood. Pulp & Pap. Mag. Can. 54(2): 54-63, illus.

Measurements were made of water absorption by Sitka spruce heartwood blocks. Results show that the rate of natural penetration of water into wood in the fiber direction at different temperatures varies with the vapor pressure of the water and the inward diffusion of the vapor. Prepenetration of dry wood with NH^3 increases the rate of absorption almost to that obtained by evacuation, and the method may have possibilities as a rapid means of impregnating dry chips with cooking liquor during pulping.

1486. _____
1956. Dimensional stabilization of wood with carbowaxes. Forest Prod. J. 6: 201-204.

Specimens of Sitka spruce were soaked in water (controls), and in 25 percent (by weight) aqueous solutions of glycerine and of carbowaxes (polyethylene glycols) before ovendrying by successive stages. With carbowaxes of molecular weights between 200 and 600, almost complete stability was obtained; with higher molecular weights and with glycerine, stability was somewhat less. Weight increase due to deposition of carbowax averaged 50 percent. Carbowaxes can be easily leached, but it was possible to fix them with an equal weight of phenolic resin. The treatment, however, is likely to cause gluing and finishing difficulties.

1487. _____
1956. Thermal degradation of wood and cellulose. Ind. & Eng. Chem. 48(3): 413-417, illus.

1488. _____
1957. Adsorption in swelling versus nonswelling systems. I. Contact area. Tappi 40: 761-765.

1489. _____
1957. Adsorption in swelling versus nonswelling systems. II. Free energy change per unit area of effective molecular contact. Tappi 40: 765-770.

1490. _____
1959. Dimensional stabilization of wood by thermal reactions and formaldehyde cross-linking. Tappi 42: 39-44, illus.

Research was carried out on samples of Sitka spruce, Douglas-fir, and redwood to assess effects of a heat stabilization treatment, alone or together with a formaldehyde cross-linking reaction. Reductions of as

much as 90 percent in swelling were attained with as little as 7 percent of bound formaldehyde, but the reaction greatly reduces the toughness and abrasion resistance of the wood.

1491. _____
1959. Bound-water diffusion into wood in the fiber direction. Forest Prod. J. 9: 27-32.

1492. _____
1960. Bound-water diffusion into wood in across-the-fiber directions. Forest Prod. J. 10: 524-528, illus.

1493. _____
1960. Combined bound-water and water-vapour diffusion into Sitka spruce. Forest Prod. J. 10: 644-648.

1494. _____
1964. Wood and cellulose science. 549 pp., illus. New York: Ronald Press Co.

1495. _____ and Wagner, Eugene.
1961. Determining the distribution of interstructural openings in wood. Forest Prod. J. 11: 141-144, illus.

1496. Stanek, Walter.
1965. Environment of Sitka spruce; a literature review. Brit. Columbia Univ. Fac. Forest., 51 pp.

Prepared under the direction of P. G. Haddock. Contains 51 references. Section on nomenclature is especially interesting.

1497. Starker, T. J.
1934. Fire resistance in the forest. J. Forest. 32: 462-467.

Lists Sitka spruce as the least fire resistant of 12 native conifers in Oregon and Washington.

1498. Steer, Henry B.
1948. Lumber production in the United States 1799-1946. U.S. Dep. Agr. Misc. Pub. 669, 233 pp., illus.

Includes one table listing annual production of spruce, hemlock, cedar, and miscellaneous lumber from 1799 to 1946.

1499. Stefansson, Valtyr.
1951. Nokkrar: stadreyndir um skograektina. [Some facts about forestry.] Árśrit Skógraektarf. Island 1950: 5-23, illus. [In Icelandic.]

Includes some data on the growth of Sitka spruce in Iceland.

1500. Stein, William I.
1966. Sampling and service testing western conifer seeds. West. Forest. & Conserv. Ass. Forest Tree Seed Counc., 36 pp.

Gives instructions for handling seed and tabulates by species procedures for conducting laboratory germination tests. Standard germination test for Sitka spruce is to place seed on top of blotters in covered petri dishes for 21 days with 20° C. night and 30° C. day temperature and at least 8 hours of fluorescent light.

1501. Stephens, F. R., and Billings, R. F.
1967. Plant communities of a tide-influenced meadow on Chichagof Island, Alaska. Northwest Sci. 41(4): 178-183, illus.

Dense Sitka spruce-western hemlock timber stands are usually found adjacent to the communities described, often with a brushy ecotone between.

1502. Sterling, E. A.
1918. Flying on wings of spruce. Amer. Forest. 24(291): 133-139, illus.

1503. Steven, H. M.
1928. Nursery investigations. Great Brit. Forest. Comm. Bull. 11, 181 pp. plus 6 plates.

1504. _____
1940. Choice of tree species in the northeast of Scotland on the basis of soil and vegetation types. Forestry 14(2): 81-85.

1505. _____
1953. Storm damage to woodlands in Scotland on January 31, 1953. Nature 171(4350): 454-456, illus.

Describes the nature and extent of storm damage and discusses problems of salvage. Few stands less than 40 feet in height were damaged. Scots pine suffered most heavily, both absolutely and relatively to Sitka spruce, larch, and Douglas-fir. Beech and oak were also blown over.

1506. Stevens, M. E.
1965. Relation of vegetation of some soils in southeastern Alaska. *In* Forest-soil relationships in North America, Chester T. Youngberg [ed.]. North Amer. Forest Soils Conf., pp. 177-188.

1507. Stevens, W. C.
1960. Twist in Sitka spruce. Timber Trades J. 232: 83-85, illus.

1508. _____ and Johnston, D. D.
1961. The seasoning properties of home-grown Sitka spruce. J. Inst. Wood Sci. (London) 7: 28-33, illus.

The seasoning properties of British-grown Sitka spruce were examined with reference to the regions and sites from which it was obtained. It was shown that this material does not tend to split or check when drying, even at high temperatures and low humidities, but does tend to twist. A very severe drying schedule was finally recommended. Statistical analysis of the data failed to show differences of any significance between the final quality of the dried material from the six regions sampled, but they indicated a highly significant difference in seasoning properties between material from different sites and also from different trees. (From authors' summary.)

1509. _____, Johnston, D. D., and Baud, M. J.
1961. The specific gravity and moisture content of freshly felled conifers. Great Brit. Forest Prod. Res. Lab. (Princes Risborough). 20 pp. (Reprinted in 1966.)

1510. _____ and Turner, N.
1942. Chemical bending: the influence of urea treatments on the bending and setting properties of wood laminations. Wood 7: 123-126, illus.

Tests on British-grown oak and beech and imported Sitka spruce confirm that urea-treated wood heated in an oven can readily be bent, but indicate that the degree of flexibility achieved is no greater than would result from immersing the material in boiling water.

1511. Stewart, G. G.
1959. Preliminary results of experiments in drain deepening in two border forests. *In* Report on forest research for the year ended March 1958. Great Brit. Forest. Comm., pp. 131-137. London: H. M. Stationery Office.

Describes the results of deepening drains from 6 to 9 inches to 24 inches in Sitka spruce forests on Molinia peat overlying clay. In one case, there was little effect on the water table between the drains whereas in the other the water level was reduced by 5 inches. In both cases, there was no significant effect on tree growth.

1512. _____
1961. Experimental introductions of alternate species into pioneer crops on poor sites. *In* Report on forest research for the year ended March 1960. Great Brit. Forest. Comm., pp. 151-166 plus 7 plates. London: H. M. Stationery Office.

1513. _____
1962. Kergord Plantations, Shetland. Forestry 35(1): 35-56 plus 2 plates.

Describes seven shelterbelts (9 acres in all) established between 1913 and 1920. They were planted as row-by-row mixtures with a number of species. In these rigorous conditions, Sitka spruce was outstandingly successful.

1514. Stirling-Maxwell, John.
1931. Sitka spruce--on poor soils and at high elevations. Forestry 5: 96-99.

Because of its ability to grow under difficult conditions, Sitka spruce has opened a new era and extended the limit of economic forestry in Britain.

1515. _____
1932. The influence of exotic conifers on silviculture in the British Isles. *In* Conifers in cultivation. Rep. Conifer Conf., Roy. Hort. Soc., London, pp. 43-54, illus.

Discusses Sitka spruce planted in the British Isles. The species is planted on a large scale, this year over 12 million seedlings having been planted by the Forestry Commission alone. Seed source is important, and seed from Queen Charlotte Islands and Alaska are suitable.

1516. Stokes, W. B.
1925. Canadian softwoods. Can. Dep. Int. Forest. Br. Circ. 19, 13 pp., illus.

1517. Stone, Herbert.
1904. The timbers of commerce and their identification. 311 pp., illus. London: William Rider & Son.

1518. Streets, R. J.
1962. Exotic forest trees in the British Commonwealth. 765 pp., illus. Oxford: Clarendon Press.

1519. Sudo, Syoji.
1955. Wood anatomical studies on the genus *Picea*. Tokyo Univ. Forest. Bull. 49: 179-204 plus 16 photos.

1520. Sudworth, G. B.
1898. Check list of the forest trees of the United States, their names and ranges. U.S. Dep. Agr. Bull. 17, 144 pp.

1521. Sudworth, George B.
1897. Nomenclature of the arborescent flora of the United States. U.S. Dep. Agr. Div. Forest. Bull. 14, 417 pp.

1522. _____
1908. Forest trees of the Pacific slope. U.S. Dep. Agr. Forest Serv., 441 pp., illus.

Describes the appearance, habitat, silvics, size, and uses of Sitka spruce.

1523. _____
1927. Check list of the forest trees of the United States, their names and ranges. U.S. Dep. Agr. Misc. Circ. 92, 295 pp.

1524. Sunley, J. G.
1955. The strength of timber struts. Great Brit. Forest Prod. Res. Spec. Rep. 9, 28 pp. plus 3 photos.

Gives the results of tests on struts of the type used in light construction. Species tested included Sitka spruce. The use of formulae in calculating strengths is discussed.

1525. _____ and Lavers, Gwendoline M.
1961. Variations in the strength and specific gravity of Sitka spruce grown in Great Britain. J. Inst. Wood Sci. 7: 15-27, illus.

Sitka spruce, widely used in afforestation by the Forestry Commission, is known to show considerable variation in quality, and the causes of this are not fully known. Variations in strength and specific gravity were

measured and related to the different geographical regions and site factors. Results indicate that the growth region has a small effect, but large variations occur between trees on the same site, although between-site and within-tree variations cannot be neglected. In addition, the relation between the "quality class" of the site and the properties is examined and the possibility of using tree girth in estimating timber properties is discussed. (From authors' summary.)

1526. Swanston, Douglas N.
1967. Debris avalanching in thin soils derived from bedrock. Pacific Northwest Forest & Range Exp. Sta. USDA Forest Serv. Res. Note PNW-64, 7 pp., illus.

Describes reconnaissance investigations of debris avalanches in shallow soils in southeast Alaska. In all cases described, slopes were steep and supported old-growth stands of Sitka spruce and western hemlock.

1527. Tailte, An Roinn.
1963. Fo-roinn na foraoiseac ta. [Report of the Minister for Lands on Forestry.] Dublin 1962/63, 38 pp. plus 4 plates, map.

Describes planting and management of Sitka spruce in Ireland.

1528. Tambs-Lyche, Helen.
1957. Bladlusangrepene på Sitka-gran. [Aphis attack on Sitka spruce.] Norsk. Skogbruk. 3(18): 470, 473, illus. [In Norwegian.]

A number of outbreaks of *Liosomaphis* (*Neomyzaphis*) *abietina* have been reported from Vestland. Slight attacks were found on Norway spruce, which may have been the original host. The insect and the damage are described.

1529. Tarkow, Harold, and Southerland, Carole.
1964. Interaction of wood with polymeric materials. I. Nature of the adsorbing surface. Forest Prod. J. 14: 184-186.

1530. _____ and Stamm, Alfred J.
1960. Diffusion through air-filled capillaries of softwoods--Part I. Carbon dioxide. Forest Prod. J. 10: 247-250, illus.

1531. _____ and Stamm, Alfred J.
1960. Diffusion through air-filled capillaries of softwoods--Part II. Water vapor. Forest Prod. J. 10: 323-324, illus.

1532. Tarrant, R. F., Isaac, L. A., and Chandler, R. F., Jr.
1951. Observations on litter fall and foliage nutrient content of some Pacific Northwest tree species. J. Forest. 49: 914-915.

Gives annual ovendry weight of litter fall, nutrient content of foliage (pounds per acre), and soil pH at three depths under several tree species including Sitka spruce.

1533. Taylor, R. F.
1929. The role of Sitka spruce in the development of second-growth in southeastern Alaska. J. Forest. 27: 532-534.

Mixed stands of Sitka spruce and western hemlock are more productive than pure stands of either species. A high percentage of spruce in the stand is desirable. Volume and quality of stands having different percentages of spruce by basal area are compared.

1534. _____
1930. Sitka spruce on the Tongass Forest looks south. Forest Worker 6(2): 14.

On the Tongass Forest most timber sales have been made on areas with southerly aspects, indicating that better quality timber occurred here. Of 37 areas on which yield studies were made, those with southerly aspects averaged 56.2 percent Sitka spruce with an average site index of 73.5 (50-year basis), whereas northeast slopes average 22.37 percent Sitka spruce with an average site index of 67.5.

1535. _____
1931. Two extremes of forest soils in southeastern Alaska. Forest Worker 7(6): 10-11.

Sample quadrats and belt transects showed that the optimum soil type for Sitka spruce reproduction consists of glacial silt and gravel lightly covered by a mold formed by the debris of pioneer plants, mostly willows, alders, and poplars.

1536. _____
1932. Plant indicators in southeastern Alaska. J. Forest. 30: 746.

In connection with a study of site prediction after the removal of virgin timber, all the important vegetation was listed on a number of plots in the hemlock-spruce type in southeastern Alaska. The lists seem to show that a definite correlation exists between the occurrence of certain of the plants noted and site index as indicated by total height at 100 years of age.

1537. _____
1933. Site prediction in virgin forests of southeastern Alaska. J. Forest. 31: 14-18.

Discusses the climax forest in southeastern Alaska, its relation to even-aged stands, and the effect of logging and other factors on the succession from one to the other. The possibility of applying ordinary yield table methods of site classification to these forests is also described.

1538. _____
1934. Yield of second-growth western hemlock-Sitka spruce stands in southeastern Alaska. U.S. Dep. Agr. Tech. Bull. 412, 30 pp., illus.

Normal yield tables for mixed even-aged stands in southeast Alaska.

1539. _____
1949. First records of growth for Alaska's young stands. USDA Forest Serv. Alaska Forest Res. Center Tech. Note 1, 1 p.

Compares actual growth records from mixed even-aged Sitka spruce-western hemlock stands with growth predicted from normal yield tables (U.S. Dep. Agr. Tech. Bull. 412) and concludes that the yield tables are reliable.

1540. _____
1949. First results of thinning in Alaska. USDA Forest Serv. Alaska Forest Res. Center Tech. Note 3, 1 p.

Describes 20-year results of thinning in a mixed western hemlock-Sitka spruce stand at age 30 years in southeast Alaska.

1541. _____
1950. Alaska forest research problems and program. Alaska Sci. Conf. Proc. 1950: 11-19.

1542. _____
1950. Cubic form class volume tables for southeast Alaska. Alaska Forest Res. Center Tech. Note 6, 6 pp.

1543. _____ and Godman, R. M.
1950. Increment and mortality in southeast Alaska's second-growth stands. J. Forest. 48: 329-331.

Second-growth stands, consisting of about half Sitka spruce and half western hemlock by volume, produce double the average volume of the climax forests in about 80 years. Diameter growth of spruce is faster than that of hemlock, except in very young stands, and increases with the diameter of the tree. Diameter growth of spruce by site classes is usually greater than that of hemlock of the same site class. Within species, each site-class growth rate is at least double the next lower rate. Within diameter classes, the mortality percent of spruce is greater than that of hemlock, but the total mortality of hemlock exceeds that of spruce. Volume growth of spruce is greater than that of hemlock except in trees of very small diameters, and increases with the diameter of the tree. Site 1 and 2 spruce and site 1 hemlock should be selected as crop trees in stands selected for thinning and pruning. (Authors' summary.)

1544. Taylor, Ray F.
1930-31. Indicator vegetation on cutover lands of southeastern Alaska. Univ. Wash. Forest Club Quart. 9(1): 21-27.

Describes habitat conditions and vegetation species associated with Sitka spruce regeneration on cutover land.

1545. _____
1932. The successional trend and its relation to second-growth forests in southeastern Alaska. Ecology 13(4): 381-391.

Successional trends are described in the climax forests of southeastern Alaska. Plants characteristically found on four common habitats are listed, and it is shown that each group roughly indicates one of four stages in the successional trend.

1546. _____
1956. Alaska. *In* World geography of forest resources, Haden-Guest, S. Wright, and Teclaff [eds.]. Amer. Geogr. Soc. Spec. Pub. 33, pp. 115-125, illus.

1547. _____ and Little, Elbert L., Jr.
1950. Pocket guide to Alaska trees. U.S. Dep. Agr. Handbook 5, 63 pp., illus.

1548. Taylor, Raymond Frank.
1934. Available nitrogen as a factor influencing the occurrence of Sitka spruce and western hemlock seedlings in the forests of southeastern Alaska. 143 pp., illus. (Ph.D. thesis on file at Yale Univ.)

1549. _____
1935. Available nitrogen as a factor influencing the occurrence of Sitka spruce and western hemlock seedlings in the forests of southeastern Alaska. Ecology 16(4): 580-602, illus.

Nitrogen in available form was found to be an important factor in the occurrence of Sitka spruce. Up to a certain level, increased available nitrogen favored spruce establishment. Ammoniacal nitrogen accumulates in organic seedbeds where oxidation to nitrates cannot occur. Spruce seedlings are scarce on such seedbeds but western hemlock seedlings are abundant. The power of nitrification varies significantly with the overstory and seedbed. Differences are discussed. Also discussed are pH values of various seedbeds.

1550. Teesdale, C. H.
1914. Relative resistance of various conifers to injection with creosote. U.S. Dep. Agr. Bull. 101, 43 pp., illus.

1551. Tennas, Magnus E., Ruth, Robert H., and Berntsen, Carl M.
1954. An analysis of production and costs in high-lead yarding. USDA Forest Serv. Pacific Northwest Forest & Range Exp. Sta. Res. Pap. 11, 37 pp., illus.

Factors influencing production and costs on a high-lead yarding operation in a 100-year-old Sitka spruce-western hemlock stand are isolated and analyzed.

1552. Thaarup, P.
1945. Bastarden Sitkagran X hvidgran. [The hybrid Sitka spruce X white spruce.] Dansk Skovforen. Tidsskr. 9: 381-384. [In Danish.]

Where Sitka spruce and white spruce are grown together, crossing occurs to such an extent that it is impossible to harvest pure Sitka seed. Brief descriptions and sample plot data are given for hybrid stands in Husby plantation and Thornby plantation.

1553. _____
1954. The afforestation of the sand dunes of the western coast of Jutland, Denmark. Advanc. Sci. 11(41): 38-41.

Discusses the development of sand-dune planting, the value and characteristics of the main species used including Sitka spruce, and costs and yields.

1554. Thelen, Rolf.
1929. Kiln drying handbook. U.S. Dep. Agr. Dep. Bull. 1136, 96 pp., illus.

Gives general kiln-drying schedules for various softwood species and special aircraft lumber schedules for several species including Sitka spruce.

1555. Thompson, Allen E.
1924. The forest resources of Washington. Univ. Wash. Forest Club Quart. 3(1): 19-32, illus.

1556. Thompson, R. T.
1959. *Polydrusus impar* (Gozis) (Col., Curculionidae) in Britain. Entomology 95(1136): 15.

The insect is reported from Sitka spruce in Rockingham Forest, Northants. It occurs commonly in the mountains of France and central Europe on *Picea abies* and *Pinus sylvestris* and has spread to conifer plantations in the Seine basin.

1557. _____ and Styles, J. H.
1958. *Otiorrhynchus niger* (F.) (Col., Curculionidae) in Britain. Entomology 94(1131): 183.

A record of the insect on Sitka spruce in Northamptonshire; the larvae attack the roots, and the adults feed on the leaves. It is believed to be the first British record of the insect, which is normally found in the mountainous regions of central and southern Europe.

1558. Thomsen, M.
1939. Angreb af *Tomicus chalcographus* paa Sitkagraner, Rødgraner, og Douglasgraner. [Attack of *T. chalcographus* on young Sitka spruce, Norway spruce, and Douglas-fir.] Forstl. Forsøgsv. Danmark 15: 199-208. [In Danish. English summary.]

In 1936, and especially in 1938, many young stands of Sitka and Norway spruce were heavily damaged by the insect. The primary cause was probably spring frost injury to the cambium, but there was evidence that most of the young trees did not succumb to the direct effect of the frost.

1559. Thulin, I. J.
1963. Forest tree improvement. New Zeal. Forest Serv. Forest Res. Inst. Rep. 1962: 36-39.

The importance of seed origin in Sitka spruce was demonstrated in a nursery trial of four provenances sown in a randomized trial. Mean heights of 2-year plants were 25 inches and 26.6 inches for California seed origins, 14.1 inches for an Oregon provenance, and 8.3 inches for a seed lot collected in one of the best stands of Sitka spruce in New Zealand. Height growth of the New Zealand origin ceased significantly earlier in the autumn than that of California provenances.

1560. _____, Will, G. M., and Bassett, C.
1958. A pilot trial of soil sterilization in a forest nursery. New Zeal. J. Forest. 7(5): 88-93, illus.

A soil sterilization trial with chloropicrin and formalin on a light-textured pumice soil resulted in a significant reduction in seedling mortality and an increase in growth. Plant analyses indicate an improvement in the availability of nutrients, particularly potash. In this respect the chloropicrin was the more effective. Species used in the trial were *Pinus radiata*, *P. nigra*, *Pseudotsuga taxifolia*, *Larix decidua*, and *Picea sitchensis*. (Authors' summary.)

1561. Titmuss, F. H.
1964. Commercial timbers of the world. Ed. 3, 277 pp., illus. London: Tech. Press, Ltd.

1562. Torgersen, Torolf R., and Baker, Bruce H.
1967. The occurrence of the hemlock looper (*Lambdina fiscellaria* (Guenee)) (Lepidoptera: Geometridae) in southeast Alaska, with notes on its biology. Pacific Northwest Forest & Range Exp. Sta. USDA Forest Serv. Res. Note PNW-61, 6 pp., illus.

The collection and subsequent identification of the hemlock looper is the first record of this insect in Alaska. About 396 acres of Sitka spruce were heavily defoliated in the outbreak. The insect is described.

1563. Toumey, James W., and Korstian, Clarence F.
1952. Seeding and planting in the practice of forestry. Ed. 3, 520 pp., illus. New York: John Wiley & Sons.

1564. _____ and Stevens, Clark L.
1928. The testing of coniferous tree seeds at the School of Forestry, Yale University 1906-1926. Yale Univ. Sch. Forest. Bull. 21, 46 pp., illus.

Germination of Sitka spruce seldom gets well underway within a period of 20 to 30 days, and usually many sound seeds remain ungerminated after a period of 50 days. Based on 14 samples, average germination capacity was 31.9 percent and maximum was 72 percent. Number of seeds per pound varied from 186,880 to 411,600. The average was 256,991.

1565. Trappe, James M.
1961. Strong hydrogen peroxide for sterilizing coats of tree seed and stimulating germination. J. Forest. 59: 828-829.

Soaking Sitka spruce seed for one-half hour in a 35-percent solution of H_2O_2 stimulated germination and sterilized seedcoats without damage to the embryo.

1566. _____
1961. Some probable mycorrhizal associations in the Pacific Northwest. III. Northwest Sci. 35(3): 91-94.

Lists the following fungi observed in mycorrhizal association with Sitka spruce: *Amanita vaginata*, *Russula delica*, *Russula emetica*, *Svillus piperatus*, *Xerocomus zelleri*.

1567. _____
1962. Fungus associates of exotrophic mycorrhizae. Bot. Rev. 28(4): 538-606.

1568. _____
1963. Some probable mycorrhizal associations in the Pacific Northwest. IV. Northwest Sci. 37(1): 39-43.

Several probable mycorrhizal associations with Sitka spruce and western hemlock are listed.

1569. _____
1964. Mycorrhizal hosts and distribution of *Cenococcum graniforme*. Lloydia 27(2): 100-106, illus.

1570. Troll, C.
1955. Der Mount Rainier und das Mittlere Cascaden-gebirge. [Mount Rainier and the middle Cascade Range.] Erdkunde 9: 264-274, illus. [In German.]

1571. Troup, R. S.
1932. Exotic forest trees in the British Empire. 259 pp. Oxford: Clarendon Press.

1572. Truax, T. R.
1930. Gluing wood in aircraft manufacture. U.S. Dep. Agr. Tech. Bull. 205, 58 pp.

1573. Tulstrup, N. P.
1951. Et gødningsforsøg I Egelund planteskole. [An experiment with fertilizers at the Egelund Nursery.] Dansk Skovforen. Tidsskr. 36(3): 105-114, illus. [In Danish.]

Plots were fertilized with combinations of N (350 kilograms $Ca(NO_3)$ 2 per hectare), P (150 kilograms 18 percent superphosphate per hectare), K (150 kilograms 40 percent K fertilizer or $(NH_4)_2SO_4$ per hectare), or with stable manure, or were left untreated before planting with 2 + 0 Sitka spruce and other species. 2P + K + N and 2N + K + P stimulated height growth of Sitka spruce whereas 2K reduced it. Results with other species are also discussed and some figures for cost of the different fertilizers are given.

1574. Turner, N.
1952. The bonding of Sitka spruce scarf joints for use in laminated beams. *In* Selected government research reports, vol. 8, rep. 14, pp. 105-109, illus. London: H. M. Stationery Office.

1575. _____
1952. The limiting radii of curvature of Sitka spruce, western hemlock, and Douglas-fir sliced laminae (with an appendix on the effect of "loose" face on such radii). *In* Selected government research reports, vol. 8, rep. 16, pp. 118-122, illus. London: H. M. Stationery Office.

1576. _____ and Dean, A. R.
1952. A new type of bent corner. Wood 17(12): 462-468, illus.

1577. _____ and Webster, C.
1947. The effect of method of conversion, i.e., sawn or sliced, on the limiting radii of curvature of Sitka spruce laminae. Great Brit. Forest Prod. Res. Lab. Sci. & Tech. Memo. 31/46-FP32 RIS38.

1578. Tusko, Frank F.
1960. Application of plantsociological principles to the studies of the forest of the Powell River Co., Ltd. in Long Bay (Louis Lake). 11 pp., illus. (Thesis on file at Univ. Brit. Columbia.)

Forest types and their silvicultural relations are described. Sitka spruce with western white pine occurs at the edges of the sphagnum-bog type. Recommended silvicultural treatment of the bog type, on biological grounds, is drainage and saddle pattern planting with western hemlock, Sitka spruce, western redcedar, and western white pine.

1579. Twerdal, M. P., and MacLean, C. D.
1957. Forest statistics for Tillamook County, Oregon. USDA Forest Serv. Pacific Northwest Forest & Range Exp. Sta. Rep. 130, 34 pp., illus.

1580. Ugolini, Fiorenzo C.
1966. Soils. *In* Soil development and ecological succession in a deglaciated area of Muir Inlet, southeast Alaska. Inst. Polar Stud. Rep. 20, Part 3, pp. 29-72, illus.

A study of soil development following recent deglaciation. Sitka spruce is a component of the biota. The influence of plants on soil development is discussed.

1581. Urbas, Janko.
1951. O Nasadh Sitke (*Picea sitchensis*) v Slovenji. [Plantations of Sitka spruce in Slovenia.] Gozd. Vestn. 9(1/2): 20-26, illus. [In Slovenian.]

A general account, which includes detailed measurements for a small plot on the Skrbsovo estate in 1948.

1582. Usher, Jack H., and Hall, Hoyt H.
1957. Forest statistics for Lincoln County, Oregon. USDA Forest Serv. Pacific Northwest Forest & Range Exp. Sta. Rep. 129, 30 pp., illus.

1583. U.S. Bureau of the Census.
1966. Lumber production and mill stocks 1964. U.S. Dep. Com. Current Ind. Rep. Ser. M24T(64)-1, 8 pp.

One of a series of annual lumber and mill stock reports prepared by the U.S. Bureau of the Census. Lists production of softwoods and hardwoods in the United States by area and by the more important lumber species. Sitka spruce is among the species reported.

1584. U.S. Corps of Engineers.
1963. Terrain study of Alaska, Part V: Vegetation. Eng. Intelligence Study EIS-301. Publ. Corps Eng., Army Map Serv., Washington, D.C.

Consists of a map approximately 32 by 46 inches, scale 1:2,500,000, showing vegetation types, one of which is "very high evergreen hemlock-spruce forest," which includes Sitka spruce.

1585. USDA Forest Service.
1957. Shrinking and swelling of wood in use. (Rev.: Information reviewed and reaffirmed.) Forest Prod. Lab. Rep. 736, 11 pp. plus 7 tables, 2 figs.

Tables show shrinkage values for Sitka spruce.

1586. _____
1961. Standard terms for describing wood. (Rev.) Forest Prod. Lab. Rep. 1169, 2 pp. plus 9 tables.

1587. _____
1963. Characteristics of Alaska woods. Forest Prod. Lab. Res. Pap. FPL-1, 64 pp., illus.

Contains information on the characteristics and utilization of 11 Alaskan woods including Sitka spruce. Mechanical characteristics, seasoning data, and preservative treatments of the species are discussed and tables summarizing strength properties, pulp processes and yields, and drying schedules are included.

1588. _____
1963. The identification of Douglas-fir wood. (Rev.) Forest Prod. Lab. Res. Note FPL-010, 2 pp.

Revises a note first published in 1923, briefly describing differences between the wood of Douglas-fir and of other softwoods used for similar purposes, including Sitka spruce. Color of heartwood is pale pinkish brown; split or dressed surfaces have a silky sheen; tangentially split or dressed surfaces have a dimpled appearance; slight exudation of resin is occasionally present; odor is not pronounced.

1589. _____
1964. Pulp yields for various processes and wood species. Forest Prod. Lab. Res. Note FPL-031, 2 pp. plus 4 tables.

Lists density, fiber length, and typical pulp yields, as obtained primarily by kraft and sulfite processes, from many softwood and hardwood species grown in the United States, including Sitka spruce.

1590. _____
1928. Growth in the spruce-hemlock type. Pacific Northwest Forest Exp. Sta. Forest Res. Note 1, 4 pp.

1591. _____
1948. Woody-plant seed manual. U.S. Dep. Agr. Misc. Pub. 654, 416 pp., illus.

Gives information on time of flowering, cone ripening, seed periodicity, time of collection, seed yields, purity, soundness, and cost of seed. Sitka spruce cones yield 8 to 20 ounces of seed per bushel. Average number of seed per pound is 210,000. Recommendations are given for seed germination tests. Average germinative capacity is 60 percent.

1592. _____
1950. The forests of Alaska. Alaska Reg., 18 pp., illus.

Contains a description of Alaska's forests and of Sitka spruce which comprises 21 percent of the coastal forest type.

1593. _____
1953. Volume tables for permanent sample plots as recommended by the Puget Sound Research Center Advisory Committee for use in western Washington. Pacific Northwest Forest & Range Exp. Sta., 2 pp. plus 28 tables.

1594. _____
1954. Sitka spruce. Useful trees of the United States--No. 9. U.S. Dep. Agr., 4 pp., illus.

1595. _____
1954. Alaska's forests. (Rev. 1963.) U.S. Dep. Agr., 8 pp.

Briefly describes Alaska's National Forests and gives timber production data. Sitka spruce supplies most of the present Alaskan requirements for saw logs and is manufactured into all the usual forms of lumber. Sitka spruce composes 34 percent of the stand.

1596. _____
1955. Chemical brush control. *In* Annual report 1954. Alaska Forest Res. Center Sta. Pap. 2, pp. 18-19.

Dense brush in plots containing western hemlock and Sitka spruce seedlings was successfully killed by an NH_4 sulfamate spray applied at the rate of 1 gallon of spray per 400 square feet (100 gallons spray or 54 pounds chemical per acre). Mortality of western hemlock seedlings was high, but Sitka spruce was killed only by direct heavy spray.

1597. _____
1955. Seasonal distribution of leader and radial growth of saplings of western hemlock and Sitka spruce. *In* Annual report 1954. Alaska Forest Res. Center Sta. Pap. 2, p. 24.

Presents growth data for Sitka spruce and western hemlock for 1 year from the Ketchikan area of the Tongass National Forest, Alaska.

1598. _____
1955. The black-headed budworm. *In* Annual report 1954. Alaska Forest Res. Center Sta. Pap. 2, pp. 26-29.

One year of heavy budworm defoliation on Sitka spruce advanced reproduction and poletimber caused leader kill in 86 percent of the dominant trees, 71 percent of the codominants, 71 percent of intermediates, and

29 percent of the suppressed trees. All current year's growth was defoliated throughout the top 16 feet of dominant spruce, the top 8 feet of codominant spruce, and the top 4 feet of the intermediate spruce.

1599. _____
1955. Wood handbook. U.S. Dep. Agr. Handbook 72, 528 pp., illus.

Contains basic information on wood as a material of construction with data for its use in design and specification. Tabular values are given for specific gravity, electrical resistance, moisture content, shrinkage, and strength.

1600. _____
1956. Wood: colors and kinds. U.S. Dep. Agr. Handbook 101, 36 pp., illus.

Contains brief descriptions and colored photos of radial, tangential, and cross-section samples of many American woods including Sitka spruce.

1601. _____
1957. Forest resources and forest industries of Lane County, Oregon. Pacific Northwest Forest & Range Exp. Sta. Forest Surv. Rep. 131, 117 pp., illus.

1602. _____
1959. General log grading rules for Sitka spruce and western hemlock. Alaska Reg. 7 pp.

1603. _____
1961. Wildling Sitka spruce. Pacific Northwest Forest & Range Exp. Sta. Annu. Rep. 1960: 73-74.

Wildling stock was compared with 3 + 0 nursery stock. At the time of planting wildling stock was twice as large, and after three growing seasons it showed better survival and had increased its initial height advantage. Wildlings are very abundant in many areas and cost $2.65 per 1,000 delivered at a 4-mile-distant planting site versus $11 per 1,000 for nursery stock. Only about half as many, however, could be planted per man-day.

1604. _____
1965. Timber trends in the United States. U.S. Dep. Agr. Forest Resource Rep. 17, 235 pp., illus.

1605. _____
1966. 1966 seed and planting stock dealers; a directory of commercial dealers in seeds and planting stock for common trees and shrubs. Tree Planters' Note 78, 29 pp.

The directory lists 12 sources of Sitka spruce seed and five sources of Sitka spruce planting stock.

1606. U.S. Department of Agriculture.
1949. Trees. The yearbook of agriculture. 944 pp., illus.

1607. _____
1961. Seeds. The yearbook of agriculture. 591 pp., illus.

1608. U.S. Department of Commerce.
1966. Product standard PS 1-66. Softwood plywood, construction and industrial. A recorded voluntary standard of the trade. Nat. Bur. Stand., 25 pp., illus.

Describes standards for grading softwood plywood by group, according to species including Sitka spruce.

1609. U.S. Spruce Production Corporation.
1919. History of spruce production division. 126 pp., illus. Portland, Oreg.: Kilham Stationery & Printing Co.

Describes organization and production records of the spruce production division, U.S. Army, and United States Spruce Production Corporation, which supplied aircraft timber during World War I.

1610. U.S. Tariff Commission.
1929. Logs of fir, spruce, cedar, or western hemlock. Report to the President of the U.S. Senate Finance Committee. 42 pp. plus map.

1611. Vaartaja, O.
1957. The susceptibility of seedlings of various tree species to *Phytophthora cactorum*. Can. Dep. Agr. Forest Biol. Div. Bi-mon. Progr. Rep. 13(2): 2.

1612. _____
1959. Evidence of photoperiodic ecotypes in trees. Ecol. Monogr. 29: 91-111, illus.

The hypothesis of photoperiodic ecotypes was tested with 38 tree species (including Sitka spruce) of 19 genera and 81 seed sources from various latitudes in the northern hemisphere. The four greenhouse test conditions differed photoperiodically but specified the same amount of light from sun and fluorescent tubes. The farther north the seed source, the greater was the response to test conditions and the longer was the maximum "critical" day length that inhibited the seedlings. Interaction of seed source and photoperiod was analyzed and recorded by these responses: (1) Duration of elongation. Under certain day lengths, elongations of northern seedlings ceased while it continued in southern seedlings. (2) Amount of growth. (3) Lateral development. Numbers of side branches and buds were restricted in northern seedlings under short days. It is suggested that the photoperiodic ecotypes have evolved as an indirect mechanism in the adaption of trees to various seasonally changing climate factors. Thus, they are only approximately similar at different sites in each latitude.

1613. _____ and Salisbury, P. J.
1961. Potential pathogenicity of *Pythium* isolates from forest nurseries. Phytopathology 51(8): 505-507.

1614. Vabre, A.
1954. L'hybride *Tsugo-Picea hookeriana* et ses parents: étude des plantules. [The hybrid *Tsugo-Picea hookeriana* and its parents: A study of the seedlings.] Trav. Lab. Forest. Toulouse 1, vol. 5, art. 15, 8 pp., illus. [In French.]

Purports to confirm that *Tsuga hookeriana* is a hybrid of *T. heterophylla* and *Picea sitchensis*.

1615. Vabre-Durrieu, A.
1954. L'hybride *Tsugo-Picea hookeriana* et ses parents: etude chromosomique et caryologique. [The hybrid *Tsugo-Picea hookeriana* and its parents: a cytological and caryological study.] Trav. Lab. Forest. Toulouse 1, vol. 5, art. 17, 4 pp., illus. [In French.]

1616. _____
1956. Le froid et les graines de quelques Abietacees. [The reaction to cold of seed of some species of Abietineae.] Trav. Lab. Forest. Toulouse 1, vol. 5, art. 29, 6 pp. [In French.]

Sitka spruce is classified tentatively as having nondormant seed.

1617. Valk, U.
1960. Eestisse introdutseeritud kuused. [Spruces introduced into Estonia.] Eesti NSV Teaduste Akad. Toimetised, Tallinn (Bioloogiline Seeria) 1, pp. 60-65 plus 4 photos. [In Estonian. English summary.]

A tabulation of exotic spruces introduced into Estonia is given. Sitka spruce is described as rare, with poor to satisfactory growth, generally sensitive to frost, cone bearing, and generally suitable for cultivation in parks and gardens.

1618. Van Campo-Duplan, and Gaussen, H.
1948. Sur quatre hybrides de genres chez les Abietinées. [Four intergeneric hybrids among the Abietineae.] Trav. Lab. Forest. Toulouse 1, vol. 4, art. 24, 14 pp., illus. [In French.]

From studies of pollen morphology, the authors conclude that mountain hemlock, *Tsuga hookeriana* Murr. = *T. mertensiana* (Bong.) Carr., is an intergeneric hybrid between *T. heterophylla* and *Picea sitchensis*, for which they propose the name *Tsugo-Picea hookeriana*. (See also review by John W. Duffield, J. Forest. 48: 440.)

1619. Van Dersal, William R.
1938. Native woody plants of the United States, their erosion-control and wildlife values. U.S. Dep. Agr. Misc. Pub. 303, 362 pp., illus.

1620. Van Goor, C. P., and Jager, K.
1961. Chemische bestrijding van ongewenst loofhout in bosculturen door stambehandeling. [Chemical control of hardwoods in plantations by stem treatment.] Ned. Bosbouw Tijdschr. 33(5): 137-138. [In Dutch. English summary.]

1621. Varty, I. W.
1953. "*Cinaropsis pilicornis*": A rare aphid attacking spruce transplants. Scot. Forest. 7(3): 86-87.

Describes the insect and reports an outbreak on 2+2 Sitka spruce transplants in Nevis nursery. Control consisted of spraying three times with an emulsion of paraffin and soft soap.

1622. Veitch, James, and Sons.
1881. A manual of the coniferae, containing a general review of the order; a synopsis of the hardy kinds cultivated in Great Britain; their place and use in horticulture.... 350 pp., illus. Chelsea: James Veitch and Sons.

1623. Venables, L. S. V., and Venables, U. M.
1948. A Shetland bird population: Kergord Plantations. J. Anim. Ecol. 17(1): 66-74 plus 2 photos.

The largest area of woodland on Shetland is at Kergord, Weisdale, where some 8 to 9 acres of mixed plantations are growing well. The dominant species are *Acer pseudoplatanus*, *Larix leptolepis*, and *Picea sitchensis*. In addition to a report on bird ecology, a short history of the plantations with a list of tree and shrub species is given.

1624. Venet, J.
1955. Le bois et les bateaux de guerre, de commerce et de plaisance. [Wood and warships, merchant vessels, and pleasure boats.] Rev. Bois Appl. 10(1): 17-24, illus. [In French.]

1625. Versepuy, Michel.
[n.d.] Nomenclature pratique des principales gymnospermes. [Illustrated catalog of the principal gymnosperms.] 111 pp., illus. Le Puy, France: Jeanne D'Arc. [In French.]

Contains brief descriptions and illustrations of many gymnosperm species, with notes on seed. Also contains a description, historical account, and photos of Versepuy seed extraction plant with information on seed procurement, handling, processing, and practical suggestions for planting.

1626. Vidakovic, Mirko.
1963. Meduvrsno krizanje Panciceve omorike (*Picea omorica* (Pancic) Purkyne) sa Sitkanskom smrcom (*Picea sitchensis* (Bong.) Carr.). [Interspecific crossing between (*Picea omorika* (Pancic) Purkyne) and Sitka spruce (*Picea sitchensis* (Bong.) Carr.).] Sumarstvo 16: 337-342, illus. [In Slovak. English summary.]

1627. Viereck, Leslie A.
1967. Botanical dating of recent glacial activity in western North America, pp. 189-204, illus. *In* Arctic and alpine environments, H. E. Wright, Jr., and W. H. Osburn [eds.]. Bloomington: Indiana Univ. Press.

1628. Vincent, Robert E.
1958. The larger plants of Little Kitoi Lake. Amer. Midland Natur. 60(1): 212-218, illus.

1629. Vite, J. P., and Rudinsky, J. A.
1959. The water-conducting systems in conifers and their importance in the distribution of trunk-injected chemicals. Boyce Thompson Inst. Contr. 20(1): 27-38, illus.

The routes by which water is conducted upward in conifers were studied by injecting acid fuchsin near the base of young to middle-aged trees. Five different patterns of translocation were detected in the sapwood of the conifers examined. These, and the way they affect distribution of the injected materials, are described. Type A, the spiral ascent, turning right, is characteristic of the investigated species of *Picea*.

1630. Volkert, Erik.
1956. Holzeigenschaften von Gastbaumarten. [Wood properties of exotic species.] Holz Als Roh- und Werkstoff 14(3): 81-86, illus. [In German.]

1631. Voute, A. D.
1947. Het optreden van den sparrenbastkever (*Dendroctonus micans* Kug.) in ons land en de mogelijkheid tot het voorkomen van de plaag. [The occurrence in Holland of *Dendroctonus micans* and possibilities of controlling this pest.] Ned. Boschbouw-Tijdschr. 19(3): 85-87.

Sitka and oriental spruces of 35 or more years of age are susceptible to attack. The life history of the insect in Holland is described.

1632. Wade, Leslie Keith.
1965. Vegetation and history of the sphagnum bogs of the Tofino area, Vancouver Island. 125 pp., illus. (M.S. thesis on file at Univ. Brit. Columbia.)

Within the study area, pure Sitka spruce stands lie adjacent to the open ocean, occupying a narrow strip along the bank and along the surface of the coastal terrace. The strip of spruce is nowhere more than a few hundred feet wide, always fronting the open ocean. It is inferred that the distribution of Sitka spruce is in some manner controlled by the presence of the open ocean. Analysis of pollen profiles in a shallow (150-centimeter) bog is described. Spruce pollen was among the tree species found.

1633. Wagener, Willis W., and Davidson, Ross W.
1954. Heart rots in living trees. Bot. Rev. 20(2): 61-134.

1634. Wakefield, W. E.
1957. Determination of the strength properties and physical characteristics of Canadian woods. Can. Dep. Northern Aff. & Natur. Resources Forest. Br. Bull. 119, 64 pp., illus.

1635. Walker, K. J. S.
1963. Sawmill study: work cycle times on a rackbench. Forest Prod. Res. (London) Spec. Rep. 17, 23 pp., illus.

1636. Wandt, Oldenburg, and Barelmann, Nordhorn.
1963. Düngungsversuche im Emsland. [Fertilizer trials in the Ems region.] Allg. Forstz. 18(42): 664-669, illus. [In German.]

1637. Wangaard, Frederick F.
1950. The mechanical properties of wood. 377 pp., illus. New York and London: John Wiley & Sons, Chapman & Hall.

1638. Warcup, J. H.
1951. The effect of partial sterilization on the occurrence of fungi in the soil. *In* Report on forest research for the year ended March 1950. Great Brit. Forest. Comm., pp. 107-110. London: H. M. Stationery Office.

1639. _____
1952. Effect of partial sterilization by steam or formalin on damping-off of Sitka spruce. Brit. Mycol. Soc. Trans. 35(4): 248-262, illus.

Three species of *Pythium* isolated from alkaline soil of an old established nursery at Ampthill were found to be parasitic to Sitka spruce seedlings. Symptoms varied from typical damping-off to a slow root-rot. Not all infected seedlings died, some surviving as stunted plants with partly diseased root system. Steam or formalin treatment markedly improved numbers and height of Sitka spruce seedlings in the first year after treatment and showed a moderate residual effect in the second year, but gave little improvement in the third year. (From author's summary.)

1640. Ward, J. D. U.
1952. A woodman's diary. 352 pp., illus. London: Routledge and Kegan Paul.

1641. Wardle, P. A.
1967. Spacing in plantations. Forestry 40(1): 47-69.

An approach to management decisionmaking is described using spacing as an example. Sitka spruce data are used to illustrate some of the main points.

1642. _____
1967. Valuation in accounts - a comparison of methods. Fourteenth IUFRO Kongress (München), Vol. VIII, Sec. 31, Working Group 1, pp. 29-51.

1643. Waring, H. D.
1953. Unexplained death of spruce in U. K. Australian Forest. 17(2): 49-54.

Nine sites have been examined on which Norway and Sitka spruce, 20 to 40 years old, are dying. The symptoms are discussed and comparisons made with the deaths of *Pinus* species which have been studied in Australia in recent years. It is suggested that the primary cause of mortality in both countries might lie in an upset of the balance between soil moisture and aeration and be accentuated by a restriction of the growing space for roots. (Author's summary.)

1644. Warrack, G. C.
1957. Natural regeneration in the Queen Charlotte Islands, p. 25. *In* Forest research review year ended March, 1957. Dep. Lands & Forests, Brit. Columbia Forest Serv.

With increased logging in the Queen Charlottes, natural regeneration can be expected to establish an adequate second crop of mixed hemlock-spruce-cedar, provided that the extent of contiguous clearcut areas is limited to 900 acres, preferably less; and encircling seed source within one-half mile is left for a period up to 10 years; and the amount of slash cover is reduced by 50 percent. Real efforts will have to be made to artificially regenerate within 3 years of clearcutting rich sites prone to early reclamation by alder, shrubs, and grasses. Protection of costly planted stock against heavy deer browsing may have to be contemplated in addition to the usual fire-protection measures. Burning has resulted in purer stands--mainly composed of Sitka spruce--but it is not a requisite to regeneration. (From author's summary.)

1645. Warren, H. V., Delavault, R. E., and Irish, Ruth I.
1952. Biogeochemical investigations in the Pacific Northwest. Geol. Soc. Amer. Bull. 63(5): 435-484.

Normal and abnormal, or anomalous, contents of copper and zinc in different organs of various ages have been determined and tabulated for the more common trees and lesser plants of the Pacific Northwest including Sitka spruce.

1646. Washington State Department of Natural Resources.
1967. Timber harvest report 1966. 73 pp.

Includes volumes of Sitka spruce. A similar report has been prepared annually since 1949.

1647. _____
1967. Washington State annual cone crop report--1967. 14 pp., illus.

Includes ratings of the 1967 Sitka spruce cone crop in the State of Washington. Similar reports have been issued since 1958.

1648. Waterman, Alma M., and Hansbrough, J. R.
1957. Microscopical rating of decay in Sitka spruce and its relation to toughness. Forest Prod. J. 7: 77-84, illus.

Sitka spruce blocks were subjected to decay in pure cultures of five brown-rot and three white-rot fungi, and the degree of decay rated in eight classes according to the extent of the presence of hyphae, bore holes, and decomposition of cell walls in the individual tracheids of a microscopical field. Decay ratings and toughness ratings were combined for test pieces cut from two boards naturally infected with *Poria monticola*.

1649. Waters, D.
1967. Brashing. Quart. J. Forest. 61(3): 234-237.

Discusses costs and benefits of removal of branches from the lower six feet of Sitka spruce stems.

1650. Watson, H.
1928. Notes on attack by *Rhizoctonia crocorum* on Sitka spruce (*Picea sitchensis*). Scot. Forest. J. 42: 58-61.

1651. Weatherell, J.
1953. The checking of forest trees by heather. Forestry 26(1): 37-40.

Experiments on podzolized heather moor at Allerston Forest have shown that a heather mulch applied around checked *Picea sitchensis*, *P. abies*, and *Chamaecyparis lawsoniana*, or more simply the elimination of living heather by surface hoeing, produces improved color and vigor of the trees. It has also been demonstrated that the addition of a nitrogenous fertilizer to checked Sitka spruce can, at least temporarily, alleviate the condition of check. (Author's summary.)

1652. _____
1957. The use of nurse species in the afforestation of upland heaths. Quart. J. Forest. 51(4): 298-304.

Some early observations on the effects of nurse crops on Sitka spruce in an experimental area on the upland heaths (of north Yorkshire) are recorded. It was found that the importance of the nurse crop was due to its capacity to reduce competition from heather, rather than to any sheltering effect. Spruce roots were found to spread under the nurse crop, especially where this was Japanese larch, when they root in the larch litter and surface soil, by then free from heather. Some problems of tending the crop so as to give the spruce room to grow without removing all the nurse species and permitting the return of the heather are explained, and various patterns for mixing the species less intimately are described. The early indications of these new experiments are given. (Author's summary.)

1653. Wechel, A. Te.
1939. Verdere gegevens over de duurzaamheid van heiningpalen. [Further data on the durability of fence posts.] Ned. Boschbouw Tijdschr. 12(9): 343-351, illus. [In Dutch.]

Sitka spruce was rated very durable.

1654. Weck, J.
1958. Zur Wiederbewaldung "Atlantischer Heiden" insbesondere in Nordwestdeutschland. [The afforestation of "Atlantic Heaths," with special reference to northwest Germany.] Allg. Forstz. 13(35): 481-485, illus. [In German.]

Norway and Sitka spruce, and Japanese larch with birch, followed by mixtures of hardwoods and high-yielding exotics are advocated.

1655. Weidner.
1949. Die Fichtengallen der Douglasienlaus (*Gilletteella cooleyi* Gill.). Bei Hamburg (Aphid. Chermesidae). [Spruce galls of *Adelges coolleyi* near Hamburg.] Z. Pflanzen Krankh. 56(7/9): 291-292, illus. [In German.]

Galls of *A. cooleyi* have been found in great numbers on *Picea sitchensis*, *P. glauca*, and *P. abies* in the Hamburg region; gall formation has previously occurred only rarely in Germany.

1656. Weisgerber, John F.
1963. Soil and cover conditions after Wyssen skyline and high-lead logging. Thirteenth Annu. Alaska Sci. Conf. Proc., pp. 88-90.

Soil disturbance was severe on 0.4 percent and mild on 2.6 percent of an area logged with the Swiss-developed Wyssen Skyline Crane. Slash accumulations were heavy on 7 percent of the logged area. Stocking with tree reproduction was 85 percent, with 1,200 to 1,500 seedlings per acre. Logging with a conventional high-lead system caused severe soil disturbance on 33.4 percent and mild disturbance on 15.1 percent of the area. Slash accumulations were heavy on 10.3 percent of the high-lead logged area. Stocking with tree reproduction was 35 percent with from 300 to 400 seedlings per acre. Species composition of both seedling stands was about 75 percent western hemlock and 25 percent Sitka spruce.

1657. Wells, Sidney D., and Rue, John D.
1927. The suitability of American woods for paper pulp. U.S. Dep. Agr. Bull. 1485: 102, illus.

1658. Wellwood, R. W.
1960. The utilization of spruce in Canada. Forest. Chron. 36: 126-135.

1659. West, W. I.
1949. A collection of Oregon woods. Oreg. State Coll. Progr. Rep. 1., Circ. 1, 31 pp., illus.

Purpose of the article is to make known this collection's existence. Seven specimens of Sitka spruce are included.

1660. West Coast Lumbermen's Association.
1922. Standard classification, grading and dressing rules for Douglas-fir, Sitka spruce, western redcedar, west coast hemlock, and Port-Orford-cedar products. 107 pp., illus. Seattle, Wash.

1661. _____
1940. Sitka spruce. 36 pp., illus.

1662. _____
1945. Sitka spruce lumber. 7 pp., illus. Portland, Oreg.

1663. _____
1956. Standard grading and dressing rules for Douglas-fir, west coast hemlock, Sitka spruce, western redcedar lumber. No. 15, 338 pp., illus. Portland, Oreg.

1664. Western Conservation Journal.
1963. Blowdown issue. Western Conserv. J. 20(4).

This issue carries several articles concerning the blowdown of October 12, 1962, which damaged many Sitka spruce stands in Oregon and Washington.

1665. Western Forestry and Conservation Association.
1929. Co-operative forest study of the Grays Harbor area. 79 pp., illus. Portland, Oreg.

Report of a survey of Grays Harbor County, Wash., with recommendations for forest protection and management of coastal forest types.

1666. _____
1953. Reports of the Pacific Northwest seeding and planting committee on various recommended reforestation practices and techniques. 69 pp. Portland, Oreg.

1667. Western Wood Products Association.
1966. 1964-65 statistical yearbook. A book of facts on western region woods. 17 pp. Portland, Oreg.

Includes data on Sitka spruce lumber production in Western States except coastal California. A supplement published in 1966 contains revised data for 1964 and preliminary data for 1966. Similar reports published in previous years.

1668. Weston, G. C.
1957. Indigenous v. exotic species in New Zealand forestry. *In* Exotic forest trees in New Zealand. Seventh Brit. Commonwealth Forest. Conf., Australia and New Zeal., pp. 37-38, illus.

1669. Westra, J. J.
1959. Een orienterend onderzoek naar de oorzaken van groeistoornissen in de bosbeplantingen in de Noordoostpolder. [A preliminary study on the causes of growth disturbances in plantations on northeast polder.] Uitvoer. Versl. Bosbouwproefsta., Wageningen 4(2): 26. [In Dutch. English summary.]

Physical properties of soils, especially structure and water economy, seemed to have more effect on growth of oak, ash, Japanese larch, Sitka spruce, and alder than chemical properties had.

1670. Whitaker, J. D.
1954. The edge effect in nursery beds. J. Oxford Univ. Forest. Soc. 4(2): 22-24.

An edge effect in nursery seedbeds of Sitka spruce was investigated. The outer rows of seedlings tend to be larger and of better color than seedlings from the center of the bed, a difference usually attributed to diminished competition for moisture. As a result of the present investigation, it is concluded that the superior growth of such marginal seedlings can be interpreted in terms of an improved N nutrition. Conversely, the severe competition for N inside the bed reduces seedling growth there and, in the absence of any marked change in the Fe or Mn uptake by the plant, leads to corresponding accumulation of these elements in the tissues.

1671. White, P. J.
1956. Note on the performance of Sitka spruce on a deep peat. Irish Forest. 13(1): 15-16.

Describes growth of a small plantation (268 trees) made in 1912 in County Clare. Mean height is now 87 feet and mean quarter girth at breast height is 11-3/4 inches.

1672. White, Phillip R.
1962. Information wanted: Letter to the editor. Amer. Forests 68(7): 4-5, illus.

The letter refers to a photograph in the May 1962 issue, showing massive tumorous growths on Sitka spruce trees. Dr. White sent in additional pictures which appeared in the July issue and pointed out that these growths also occur on white spruce.

1673. Whitford, H. N., and Craig, R. D.
1918. Forests of British Columbia. 409 pp., illus. Ottawa: Can. Comm. Conserv.

1674. Wiedemann, Alfred Max.
1966. Contributions to the plant ecology of the Oregon coastal sand dunes. 270 pp. (Ph.D. thesis on file at Oreg. State Univ.. Corvallis.) Diss. Abstr 27(9): 3005-B.

Describes plant succession on areas where the sand is eroded by wind to, or near, the water table. Vegetation develops into an impenetrable thicket with increasing dominance of *Pinus contorta* and *Picea sitchensis*. Eventually the shorter lived pine dies out leaving a forest of spruce.

1675. Will, G. M.
1962. The uptake of nutrients from sterilized forest-nursery soils. New Zeal. J. Agr. Res. 5(5/6): 425-432, illus.

Soil sterilization trials were carried out in seven nurseries in the North and South Islands to test the possibility of increasing productivity by this means. Even where soil pathogens were not a problem, seedling growth, including Sitka spruce, was improved. Chloropicrin proved more effective than formaldehyde. The greatest increases in growth and nutrient (N, P, and K) uptake occurred in pumice-soil nurseries. However, in these soils, the beneficial effect lasted for 1 year only--thereafter growth and nutrient uptake were reduced. (From author's summary.)

1676. Williamson, Richard L.
1965. Silvicultural and economic aspects of removal of scattered overmature trees from a well-stocked pole stand in the Sitka spruce-western hemlock type. (M.F. thesis on file at Oreg. State Univ., Corvallis.)

Financial analysis showed an economic advantage for immediate removal of a scattered old-growth Douglas-fir overstory from a well-stocked 38-year-old stand of Sitka spruce and western hemlock. Subsequent growth of the young stand was proportional to residual volume; decay in logging wounds had little effect on net growth.

1677. Wilmes, L. W.
1953. De aanleg van de beplantingen en de boscomplexen in de Noordoostpolder. [Tree plantings and the forest in the northeast polder.] Van zee tot Land 9: 2-63.

Describes plantings along roads, on farmlands, and around cities of the northeastern polder in Holland. In one area where there is peat, the main species are Sitka spruce, ash, and sycamore.

1678. Wilson, J. W.
1964. Wood characteristics. III: Intra-increment physical and chemical properties. Summary of studies in progress at UBC. Pulp & Pap. Res. Inst. Can. Res. Note 45, 9 pp.

1679. _____ and Wellwood, R. W.
1964. Intra-increment chemical properties of certain western Canadian coniferous species, pp. 551-559, illus. *In* Cellular ultrastructure of woody plants, Wilfred A. Cote [ed.]. Advance. Sci. Seminar Pinebrook Conf. Center Proc. Syracuse: Syracuse Univ. Press.

1680. Wilson, Sinclair A.
1929. Key to native trees of Oregon. Part I. Conifers and yews (Gymnosperms). Compiled in cooperation with Pacific Northwest Forest Exp. Sta. 2 pp.

1681. Winjum, Jack K., and Cummings, W. H.
1961. Effects of N, P, and K fertilizers on nursery-grown trees and shrubs common to Douglas-fir forests. Weyerhaeuser Co. Forest. Res. Note 43, 12 pp., illus.

In an effort to produce vigorous plants in the nursery, for herbicide trials, N, P, and K were applied at various rates in spring 1958 and 1959 to 16 species of the Douglas-fir region (five conifers, including Sitka spruce, six hardwoods, four shrubs, and one fern). Responses are discussed.

1682. Winkenwerder, Hugo.
1914. Short keys to the native trees of Oregon and Washington. Ed. 3, 16 pp. Seattle: Imperial Pub. Co.

1683. Wood, Lyman W.
1960. Variation of strength properties in woods used for structural purpose. USDA Forest Serv. Forest Prod. Lab. Rep. 1780, 11 pp. plus 21 graphs, 3 tables.

A survey of the variability of strength properties in southern yellow pine, Douglas-fir, Sitka spruce, western hemlock, eastern hemlock, Ponderosa pine, white oak, northern red oak, and red gum. (From author's summary.)

1684. Wood, R. F.
1950. Provenance studies. *In* Report on forest research for the year ended March 1949. Great. Brit. Forest. Comm., pp. 50-56. London: H. M. Stationery Office.

Sitka spruce from the Masset District, Queen Charlotte Islands, B.C., showed the greatest height growth in an experiment at Kielder.

1685. _____
1955. Studies of northwest American forests in relation to silviculture in Great Britain. Great Brit. Forest. Comm. Bull. 25, 42 pp. plus 35 photos.

During 1952 and 1953, the author visited the forests of British Columbia and the Pacific Northwest of the United States. He discusses growth of the principal tree species (*Picea sitchensis*, *Pseudotsuga taxifolia*, *Tsuga heterophylla*, *Thuja plicata*, *Pinus contorta*, *Abies amabilis*, and *A. grandis*), as observed in northwest America, with particular reference to forestry practice in the British Isles. Climatic comparisons, distribution and limits of species, silvicultural notes on the principal species and associations, and provenance questions are included.

1686. _____
1955. The use in Great Britain of certain northwest American species. Empire Forest. Rev. 34(3): 247-251.

Gives some notes on *Pseudotsuga taxifolia*, *Picea sitchensis*, *Tsuga heterophylla*, and *Pinus contorta* and their natural habitat, discusses current planting practice with these species in Great Britain, and suggests the best growing conditions for each.

1687. _____
1965. Review of the year's work. *In* Report on forest research for the year ended March 1964. Great Brit. Forest. Comm., pp. 1-10. London: H. M. Stationery Office.

1688. _____
1967. Review of the year's work. *In* Report on forest research for the year ended March 1967. Great Brit. Forest. Comm., pp. 5-21. London: H. M. Stationery Office.

1689. _____ and Bryan, John.
1962. The silviculture and quality of Sitka spruce grown in Great Britain. Fifth World Forest. Congr. Proc. (Seattle) 1960, 3(sect. 6B): 1372-1374. [French and Spanish summary.]

1690. _____ and Holmes, G. D.
1957. Improvement of checked plantations. *In* Report on forest research for the year ended March 1957. Great Brit. Forest. Comm., pp. 39-40. London: H. M. Stationery Office.

1691. _____ and Holmes, G. D.
1957. Chemical bark peeling. *In* Report on forest research for the year ended March 1957. Great Brit. Forest. Comm., pp. 43-44. London: H. M. Stationery Office.

Trials of chemicals with a lower mammalian toxicity than sodium arsenite are described.

1692. _____ and Holmes, G. D.
1959. Silvicultural investigations in the forest: (A) South and central England and Wales: Improvement of checked plantations. *In* Report on forest research for the year ended March 1958. Great Brit. Forest. Comm., pp. 40-41. London: H. M. Stationery Office.

Three years after application of six hundredweight potassic superphosphate per acre, 20-year Sitka spruce is 5 to 6 feet high versus

controls still in check at 1-1/2 to 2 feet. Large-scale mechanical broadcasting of triple superphosphate at rates up to six hundredweight per acre has been carried out, to evaluate the practicability and economics of such treatment. Elimination of dense heather by spraying with 2, 4-D had relatively little effect on crop growth in the first season after treatment, but the effects of added phosphate were greater in such cleared areas.

1693. _____, Holmes, G. D., and Fraser, A. I.
1962. Silvicultural investigations in the forest: (A) South and central England and Wales: wind stability studies. *In* Report on forest research for the year ended March 1961. Great Brit. Forest. Comm., pp. 29-30. London: H. M. Stationery Office.

Pulling-over trials have been carried out on Sitka spruce, 33 years old, growing on peat up to 24 inches deep, above mineral soils of different characteristics. Drainage increased the depth of rooting and slightly increased tree stability. Most trees rooted to the full depth of the peat, and the degree of root penetration into the mineral soil had more influence on stability than the total depth of rooting. For a given height, trees of high basal area tended to be more stable than trees of lesser basal area.

1694. _____ and Lines, R.
1959. Provenance studies: Sitka spruce. *In* Report on forest research for the year ended March 1958. Great Brit. Forest. Comm., pp. 55-57. London: H. M. Stationery Office.

1695. _____, Lines, R., and Aldhous, J. R.
1960. Provenance studies: Sitka spruce. *In* Report on forest research for the year ended March 1959. Great Brit. Forest. Comm., pp. 50-52. London: H. M. Stationery Office.

Sitka spruce provenance experiments in the north have shown highly significant differences in the percentage of trees with dead leaders following frost damage. A close relationship exists between the damage and the occurrence of trees with Lammas shoots, these being much more frequent in the Washington provenances than in those from the Queen Charlotte Islands. The possibility of using Washington or other southern seed sources for nonfrosty localities is discussed.

1696. _____ and Nimmo, M.
1962. Chalk Downland afforestation. Great Brit. Forest. Comm. Bull. 34, 45 pp. plus 24 plates.

1697. _____ and Westall, A. W.
1955. The forest plots. *In* Guide to National Pinetum and forest plots at Bedgebury. Ed. 2. Great Brit. Forest. Comm., pp. 23-56 plus 10 plates.

1698. Woods, J. B., Jr., and Hann, J. H.
1949. Preliminary report: the Cochran airplane seeding experiment. Oreg. State Board Forest. Res. Bull. 2, 36 pp., illus.

In 1945-46, 100 acres in Tillamook County, Oreg., were seeded by airplane with a mixture of five parts Port-Orford-cedar, two parts Sitka spruce, and one part western hemlock by weight, at a rate of one-half pound per acre.

1699. Wooldridge, David Dilley.
1961. Environmental factors related to growth and management of western hemlock (*Tsuga heterophylla* (Raf.) Sarg.). Diss. Abstr. 22(5): 1337.

1700. Worsley, R. G. F.
1959. The processing of pollen. Silvae Genet. 8(5): 143-148, illus.

1701. Worster, H., and Sugiyama, B. K.
1962. The carbohydrate content and composition of some western woods related to growth factors. Pulp & Pap. Mag. Canada 63(8): T395-T401, illus.

Sitka spruce contained 75 percent holocellulose compared with 72.4 percent for western hemlock and 73.1 percent for Pacific silver fir. Holocellulose isolated from fast growing Sitka spruce contained more hexosan and glucan and less pentosans than slow growing trees. Highly significant relationships exist between wood holocellulose content, site index of a stand of timber, and wood specific gravity for Sitka spruce.

1702. Worthington, Norman P.
1955. A comparison of conifers planted on the Hemlock Experimental Forest. USDA Forest Serv. Pacific Northwest Forest & Range Exp. Sta. Res. Note 111, 5 pp.

In 1952, 1,000 Sitka spruce 3-0 seedlings were planted on the Hemlock Experimental Forest in cooperation with the St. Regis Paper Co. After 3 years survival percent was 66 percent, average height 5.4 feet. Rabbits damaged spruce only rarely, in contrast with other species. Sitka spruce appears capable of successful establishment.

1703. Wraber, Maks.
1951. Tuje drevesne vrste v naših gozdovih. [Foreign tree species in our forests.] Gozd. Vestn. 9(4): 94-103. [In Slovene.]

1704. Wright, Ernest, and Isaac, Leo A.
1956. Decay following logging injury to western hemlock, Sitka spruce, and true firs. U.S. Dep. Agr. Tech. Bull. 1148, 34 pp., illus.

The entry and spread of decay following logging injury to residual trees in partially cut stands were studied in western Washington and Oregon. A total of 27 different fungi were identified. On Sitka spruce, *Fomes pinicola* caused 34 percent; *Stereum* spp., 15 percent; and *Lentinus kauffmanii*, 11 percent of infections. Decay rate was slower for spruce than for hemlock at the start, but faster once the decay was established.

1705. _____, Rhoads, Arthur S., and Isaac, Leo A.
1947. Decay losses following logging injury in partially cut stands of western hemlock and Sitka spruce. Timberman 48(10): 52, 54, 72, 74, 76, illus.

Approximately half of the reserve trees injured by logging became infected with wood-rotting fungi in a period varying from 5 to 32 years. The decay following logging injury amounted to 41 percent of the calculated gross increment since logging of the western hemlock trees studied and

43 percent of the growth of Sitka spruce. On all areas studied there was windfall loss and mortality from causes in addition to decay. Measures to reduce losses are discussed.

1706. Wright, Jonathan W.
1955. Species crossability in spruce in relation to distribution and taxonomy. Forest Sci. 1: 319-349.

The result of 6 years' artificial-pollination experiments with 70 interspecific combinations is described. Detailed range maps are given and the comparative morphology of 31 species is tabulated. From the range, and from genetic and morphological data, it is concluded that *Picea glauca, P. engelmannii, P. pungens,* and *P. sitchensis* have a common, relatively recent origin and are probably related to Old World species through *P. jezoensis* of Japan. Crossability barriers appear to have arisen mainly from genic differentiation following isolation. Introgression is observable in western North America and in eastern Europe now and has probably played a significant role in the past.

1707. _____
1962. Genetics of forest tree improvement. FAO Forest. & Forest Prod. Stud. 16, 399 pp., illus.

1708. _____ and Finn, Raymond F.
1960. A bibliography on forest genetics and forest tree improvement, 1956-1957. U.S. Dep. Agr. Misc. Pub. 808, 85 pp.

Twenty-one references pertain to the genus *Picea* and 14 to *P. sitchensis*.

1709. _____ and Rudolf, Paul O.
1962. A bibliography on forest genetics and forest tree improvement, 1958-1959. U.S. Dep. Agr. Misc. Pub. 906, 93 pp.

Twenty-four references pertain to the genus *Picea* and 16 to *P. sitchensis*.

1710. Wright, K. G., and Baisinger, D. H.
1956. The silvicultural importance of the Sitka spruce weevil (*Pissodes sitchensis*) in coastal Oregon and Washington. Soc. Amer. Forest. Proc. 1955: 64-67.

It appears that hemlock will eventually dominate Sitka spruce in Youngs River plantation, Oreg., because of damage to spruce from *Pissodes sitchensis*. Intensity of weevil attack increases farther from the coast, with stands in the coastal fog belt relatively unaffected.

1711. Wright, Kenneth H.
1960. Sitka-spruce weevil. U.S. Dep. Agr. Forest Pest Leafl. 47, 6 pp., illus.

Describes the life stages, habits, damage, and control measures. The Sitka-spruce weevil (*Pissodes sitchensis* Hopk.) is the most serious insect enemy of young Sitka spruce throughout the range of the host tree in Oregon, Washington, and British Columbia. Intensive search has failed to locate the insect in Alaska.

1712. Wright, T. W.
1959. Use of fertilizers in the afforestation of deep peat. J. Sci. Food Agr. 10(12): 645-650, illus.

Phosphorus is frequently the primary factor limiting tree growth on deep peat. Phosphate manuring combined with deep plowing results in successful establishment on all but the worst sites. Foliage analysis has recently proved successful in diagnosing P deficiency. Recent studies have shown that, as the trees mature, natural supplies of other nutrients, particularly K, may become exhausted. Tabulated results are given for Sitka spruce.

1713. Wu, Yeng-Tsu.
1964. Intra-increment lignin content of five western Canadian coniferous woods. 43 pp. (M.S. Forestry thesis on file at Univ. Brit. Columbia.)

Lignin contents of extracted free wood meals prepared from three adjacent rings of mature wood, sampled at breast height, were determined according to the micro-method of Johnson, Moore, and Zank. Lignin content of Sitka spruce differed significantly within portions of growth increment. No significant differences were found between growth rings, but a slight increase in lignin content with age was observed. Early wood was higher in lignin content than late wood. Lignin contents were in the decreasing order of: hemlock, cedar, Pacific silver fir, Douglas-fir, and Sitka spruce.

1714. Wu, Y.-T., and Wilson, J. W.
1967. Lignification within coniferous growth zones. Pulp & Pap. Mag. Can. 68(4): T-159-T-164, T-171, illus.

1715. Wyckoff, J. M.
1923. The lumbering situation in Alaska. Lumber World Rev., Chicago. (November 10.) Pp. 64-66, illus.

1716. Wyman, Donald.
1943. Simple foliage key to the hemlocks and spruces. Arnoldia 3(11): 57-64, illus.

1717. Yeatman, C. W.
1955. Tree root development on upland heaths. Great Brit. Forest. Comm. Bull. 21, 72 pp. plus 32 photos and 29 diagrams.

Describes investigations of the root development of the principal conifers used extensively in plantations established on the upland heaths of northeast England and Scotland. Species include Japanese larch, Scots pine, Sitka spruce, lodgepole pine, and Corsican pine.

1718. Yde-Andersen, A.
1961. *Polyporus schweinitzii* Fr. i naletraebevoksninger. [*Polyporus schweinitzii* in conifer stands.] Friesia (Copenhagen) 6(5): 347-355, illus. [In Danish. English summary.]

A description of the fungus, its hosts, biology, etc., including observations on Danish permanent sample plots, where, of 15 sites investigated, four were found to be infected. Infection was most common and rot most developed in stands over 30 years old.

1719. Ying-pe, Chang.
1954. Bark structure of North American conifers. U.S. Dep. Agr. Tech. Bull. 1095, 86 pp., illus.

1720. Yokota, Tokuo, and Tarkow, Harold.
1962. Hygrothermal properties of wood. Forest Exp. Sta. Bull. (Meguro, Tokyo) 135: 73-88, illus. [In Japanese. English summary.]

1721. _____ and Tarkow, Harold.
1962. Changes in dimension on heating green wood. Forest Prod. J. 12: 43-45, illus.

Describes tests with specimens of green Sitka spruce heated under water. During the first heating to 80° C., volume and tangential dimensions increased, followed by a further increase on cooling to 30°, but subsequent heatings caused shrinkage.

1722. Yuen San Chen, Peter, and Hossfeld, Ralph.
1964. Effect of viscosity on permeability of Sitka spruce to aqueous glycerin. Tappi 47: 750-752, illus.

1723. Zach, L. W.
1951. Distribution of volume in southeast Alaska trees. USDA Forest Serv. Alaska Forest Res. Center Tech. Note 10, 1 p.

1724. Zach, Lawrence W.
1950. A northern climax, forest or muskeg? Ecology 31(2): 304-306.

In southeast Alaska, present logging operations are in subclimax stands which are often the pioneer or invasion forest types usually having a large proportion of Sitka spruce following glacial recession, river valley filling, landslides, windthrow, fire, and old cuttings. Older stands have progressed to an all-aged condition and are more defective and less valuable commercially. The author theorizes that these stands may be merely a later stage in a progressive succession to muskeg within the altitudinal and gradient limits of peat formation.

1725. Zak, B.
1965. Aphids feeding on mycorrhizae of Douglas-fir. Forest Sci. 11: 410-411, illus.

Aphids similar to *Pemphigus piceae* were observed on seedling *Tsuga heterophylla* and *Picea sitchensis*.

1726. Zareba, Ryszard.
1958. Obecny stan powierzchni doswiadczalnych z egzotami w Wirtach. [The state of the Wirty exotic trial plots today.] Sylwan 102(2): 45-61, illus. [In Polish.]

Species tried include Sitka spruce.

1727. Zehetmayr, J. W. L.
1951. Experiments in planting of upland heaths. *In* Report on forest research for the year ended March 1950. Great Brit. Forest. Comm., pp. 27-33. London: H. M. Stationery Office.

1728. _____
1952. Persistence of late-flushing characters in Norway and Sitka spruce. *In* Report on forest research for the year ended March 1951. Great Brit. Forest. Comm., pp. 82-83. London: H. M. Stationery Office.

1729. _____
1954. Experiments in the economics of brashing with special reference to some problems in experimental technique. Eleventh IUFRO Congress Proc. (Rome), 1953, part 2, sect. 32: 1036-1042.

1730. _____
1954. Experiments in tree planting on peat. Great Brit. Forest. Comm. Bull. 22, 110 pp. plus 25 photos.

Summarizes the results of numerous experiments carried out in various parts of Great Britain over a number of years, which have dealt mainly with methods of establishing crops of trees on peat.

1731. _____
1957. A trial of compost in planting on peat. *In* Report on forest research for the year ended March 1956. Great Brit. Forest. Comm., pp. 139-142. London: H. M. Stationery Office.

1732. _____
1960. Afforestation of upland heaths. Great Brit. Forest. Comm. Bull. 32, 145 pp. plus 34 photos.

The upland heaths comprise heather-clad land among the hills along the east side of Scotland and northern England. They are distinct from the peat-covered lands farther west.

1733. _____ and Farquhar, J.
1956. Pruning of conifers by disbudding. *In* Report on forest research for the year ended March 1955. Great Brit. Forest. Comm., pp. 102-106, illus. London: H. M. Stationery Office.

The method has interesting possibilities for Scots and Corsican pines and possibly even for Norway and Sitka spruces. After 6 years, the reduction in height growth through disbudding is not severe, though there is a considerable loss in girth increment. Fast-growing Douglas-fir has proved unsuitable for disbudding.

1734. Zeller, S. M., and Goodding, L. N.
1930. Some species of Atropellis and Scleroderris on conifers in the Pacific Northwest. Phytopathology 20: 555-567, illus.

1735. Zentsch, W., and Jahnel, H.
1960. Aussaatversuche mit stratifiziertem Forstsaatgut im Staatlichen Forstwirtschaftsbetrieb Rovershagen. [Tests with stratified seed at Rovershagen State Forest Estates.] Forst- und Jagdzeit. 10(2): 81-83, illus. [In German.]

1736. Ziller, W. G.
1954. Studies of western tree rusts. 1. A new cone rust on Sitka spruce. Can. J. Bot. 32: 432-439 plus 8 photos.

A new cone rust has been found damaging seed of Sitka spruce on the Queen Charlotte Islands and a new *Chrysomyxa* has been found on *Moneses* uniflora in the same area. Field observations, controlled inoculations, and similarity of markings on aeciospores and urediniospores have led to the conclusion that the cone rust is the aecial stage of an undescribed *Chrysomyxa*. The rust is described and has been named *C. monesis*. Surface sterilization of the spruce seed before export is recommended. (Author's summary.)

1737. _____
1957. Fungi of British Columbia deposited in the herbarium of the Forest Biology Laboratory, Victoria, B.C. Can. Dep. Agr. Forest Biol. Lab., 59 pp.

Contains a check list of fungi, showing host of each. Fungi are also listed by host. Sitka spruce is listed as host for 61 fungi.

1738. Ziller, Wolf G.
1965. Studies of western tree rusts. VI. The aecial host ranges of *Melampsora albertensis*, *M. medusae*, and *M. occidentalis*. Can. J. Bot. 43: 217-230.

Picea sitchensis seedlings inoculated with basidiospores of *Melampsora* spp. appeared to be highly resistant to infection. One percent of seedlings became infected in each case.

1739. Zim, Herbert S., and Martin, Alexander C.
1952. Trees: a guide to familiar American trees. 157 pp., illus. New York: Simon & Schuster.

1740. Zitzewitz, H. von.
1964. Zur empfindlichkeit verschiedener Holzarten gegen einige chemische unkrautbekampfungsmittel. [The sensitivity of various tree species to certain herbicides.] Forst- und Holzwirtsch. 19(5): 87-90. [In German.]

Describes the effects of dalapon on Scots pine, Norway spruce, larch, and beech, and of simazine and gesaprim on Douglas-fir, Sitka spruce, larch, *Acer pseudoplatanus*, and beech, when these herbicides were used for grass control in plantations. All species tolerated dalapon well (apart from Scots pine, which needed special care), if sprayed outside the growing season and if strength of the spray was regulated according to the species and conditions. Trials confirmed that simazine is effective on broadleaved species but is rapidly inactivated by raw humus. Gesaprim appears to be unsuitable for this purpose.

1741. Zycha, H.
1955. Eine Krebserkrankung der Sitka-Fichte (*Picea sitchensis* (Bong.) Carr.). [A canker disease of Sitka spruce.] Forstwiss. Centralbl. 74(9/10): 293-305, illus. [In German.]

Describes a canker disease of Sitka spruce found for the first time in Germany. The probable causal agent is *Nectria cucurbitula*. The disease is not considered important enough to require limiting the planting of Sitka spruce in Germany.

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Yield tables 112, 220, 228, 526, 639, 646, 842, 866, 899, 908, 912, 1056, 1082, 1094, 1120, 1121, 1217, 1314, 1411, 1537, 1538, 1539

COMMON AND SCIENTIFIC NAMES OF VEGETATION MENTIONED IN LITERATURE REFERENCES

Alaska-cedar	*Chamaecyparis nootkatensis* (D. Don) Spach
Ash	*Fraxinus* spp.
Balsam fir	*Abies balsamea* (L.) Mill.
Balsam poplar	*Populus tacamahaca* Mill.
Black spruce	*Picea mariana* (Mill.) B.S.P.
Blue spruce	*Picea pungens* Engelm.
Bracken	*Pteridium aquilinum* (L.) Kuhn. var. *pubescens*
Corsican pine	*Pinus nigra Poiretiana* (Ant.) Aschers. & Graebn.
Deodar cedar	*Cedrus deodara* (Roxb.) Loud.
Douglas-fir	*Pseudotsuga menziesii* (Mirb.) Franco
Eastern white pine	*Pinus strobus* L.
Engelmann spruce	*Picea engelmannii* Parry
European beech	*Fagus sylvatica* L.
European larch	*Larix decidua* Mill.
Grand fir	*Abies grandis* (Dougl.) Lindl.
Heather	*Calluna vulgaris* (L.) Hull.
Japanese larch	*Larix leptolepis* (Sieb. & Zucc.) Gord.
Lawson cypress	*Chamaecyparis lawsoniana* (A. Murr.) Parl.
Lodgepole pine	*Pinus contorta* Dougl.
Lutz spruce	*Picea* X *lutzii* Little
Mjombo	*Brachystegia boehmii* Taub.
Monterey pine	*Pinus radiata* D. Don
Morabukea	*Mora gonggrijpii* (Kleinh.) Sandw.
Mountain hemlock	*Tsuga mertensiana* (Bong.) Carr.
Mountain pine	*Pinus mugo* Turra

Muputu	*Brachystegia spicaeformis* Benth.
Noble fir	*Abies procera* Rehd.
Norway spruce	*Picea abies* (L.) Karst.
Oriental spruce	*Picea orientalis* (L.) Link.
Pacific silver fir	*Abies amabilis* (Dougl.) Forbes
Pacific yew	*Taxus brevifolia* Nutt.
Ponderosa pine	*Pinus ponderosa* Laws.
Port-Orford-cedar	*Chamaecyparis lawsoniana* (A. Murr.) Parl.
Red alder	*Alnus rubra* Bong.
Redwood	*Sequoia sempervirens* (D. Don) Endl.
Salmonberry	*Rubus spectabilis* Pursh.
Scotch broom	*Cytisus scoparius* (L.) Link.
Scots pine	*Pinus sylvestris* L.
Serbian spruce	*Picea omorika* (Pancic) Purkyne
Sessile oak	*Quercus petraea* (Matt.) Lieb.
Silver fir	*Abies alba* Mill.
Sitka alder	*Alnus sinuata* (Reg.) Rydb.
Sitka spruce	*Picea sitchensis* (Bong.) Carr.
Subalpine fir	*Abies lasiocarpa* (Hook.) Nutt.
Sugar maple	*Acer saccharum* Marsh.
Sycamore maple	*Acer pseudoplatanus* L.
Western hemlock	*Tsuga heterophylla* (Raf.) Sarg.
Western redcedar	*Thuja plicata* Donn
White spruce	*Picea glauca* (Moench) Voss
Yeddo spruce	*Picea jezoensis* (Sieb. & Zucc.) Carr.

The mission of the PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION is to provide the knowledge, technology, and alternatives for present and future protection, management, and use of forest, range, and related environments.

Within this overall mission, the Station conducts and stimulates research to facilitate and to accelerate progress toward the following goals:

1. Providing safe and efficient technology for inventory, protection, and use of resources.
2. Development and evaluation of alternative methods and levels of resource management.
3. Achievement of optimum sustained resource productivity consistent with maintaining a high quality forest environment.

The area of research encompasses Oregon, Washington, Alaska, and, in some cases, California, Hawaii, the Western States, and the Nation. Results of the research will be made available promptly. Project headquarters are at:

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